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## THESIS

**CIVIL TILTROTOR (CTR) APPLICATIONS: A  
DEPENDENCE ON DEFENSE DEVELOPMENT  
AND PROCUREMENT OF THE MV-22 OSPREY**  
by

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March 1996

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DEPENDENCE ON DEFENSE DEVELOPMENT  
AND PROCUREMENT OF THE MV-22 OSPREY**

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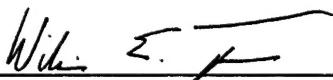
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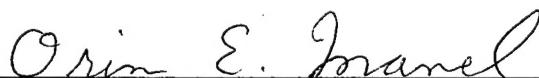


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## ABSTRACT

Tiltrotor technology has been proven mature and technically feasible through well over 40 years of Government research and development, and three generations of tiltrotor aircraft. The Defense Department is moving forward with development of the MV-22 Osprey and should reach a full rate production decision in the near future. Despite a lucrative market for civil applications of tiltrotor technology, as of 1996, there has been no firm commitment to develop a civil tiltrotor (CTR). The purpose of this thesis was to examine whether Defense development and procurement of the MV-22 Osprey is a prerequisite to commercial development of a tiltrotor. This thesis focused on the barriers to introducing the CTR, and how Government efforts and the MV-22 have been influential in overcoming those barriers. There are two principal findings. First, tiltrotor technology has progressed to the point where CTR applications are dependent on the MV-22, only to the extent that without the benefit of MV-22 production, demonstration, and operational experience, the CTR's arrival will be significantly delayed. Second, technology is not the most critical consideration. The most critical barrier to successful fielding of a CTR, is a systems integration problem, primarily centered around the lack of a supporting infrastructure.



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## LIST OF ACRONYMS

AAC	Advanced Acquisition Contracts
AGL	Above Ground Level
ATCS	Air Traffic Control System
ATL	Atlanta
BOS	Boston
CAD	Computer Aided Design
CAM	Computer Aided Manufacturing
CE	Concept Exploration
CPIF	Cost Plus Incentive Fee
CTOL	Conventional Takeoff and Landing
CTR	Civil Tiltrotor
CTRDAC	Civil Tiltrotor Development Advisory Committee
dBAs	Decibels
DEA	Drug Enforcement Agency
DEN	Denver
DFW	Dallas/Fort Worth
DLSIE	Defense Logistics Studies Information Exchange
DOD	Department of Defense
DOT	Department of Transportation
DSARC	Defense Systems Acquisition Review Council
EMD	Engineering and Manufacturing
EUROFAR	European Future Advanced Rotorcraft
FAA	Federal Aviation Administration
FY	Fiscal Year
HMX-1	Marine Helicopter Squadron One
IAC	Interim Airworthiness Criteria
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
IMC	Instrument Meteorological Conditions
IRA	Independent Risk Assessment
JFK	John F. Kennedy
JSOR	Joint Services Operational Requirement
JTAG	Joint Technology Assessment Group
JVMX	Joint Multi-Mission Vertical Lift
JVX	Joint Vertical Lift
LAX	Los Angeles
LGA	Laguardia
LRIP	Low Rate Initial Production

MIA	Miami
MILSPECs	Military Specifications
MLR	Medium Lift Replacement
MOU	Memorandum of Understanding
MPH	Miles Per Hour
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NM	Nautical Miles
NPS	Naval Postgraduate School
OEI	One Engine Inoperative
ORD	Chicago
OSD	Office of the Secretary of Defense
RDT&E	Research, Development, Test and Evaluation
RFP	Request for Proposal
SFO	San Francisco
SHP	Shaft Horsepower
STOL	Short Takeoff and Landing
USC	United States Code
V/STOL	Vertical/Short Takeoff and Landing
VTOL	Vertical Takeoff and Landing

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## I. INTRODUCTION

Bell Helicopters and the National Aeronautics and Space Administration (NASA) helped pioneer tiltrotor technology as far back as the mid-1950s, beginning with the XV-3, a developmental prototype. Years later the two organizations developed the XV-15, which captivated audiences in attendance at the Paris Air Show during its public debut in 1981. [Ref.1] Since then, literally thousands of potential investors and aviation industry leaders have observed this advanced technology demonstration. They have been awed by its capabilities, and enticed by its promising potential for employment across the entire spectrum of military and civil markets. [Ref.1]

It may be asked: Why is this unique aviation concept that combines the capabilities and advantages of a helicopter, with those of a fixed-wing turboprop aircraft, so significant? [Ref.2:p.vii]. As Congressman Pete Geren, a Representative from Texas pointed out in testimony before Congress:

The versatility and maneuverability of this innovative aircraft make it ideally suited for so many missions, for which traditional helicopters or airplanes are impractical. Some of these missions will include new uses for the military special operations drug interdiction, disaster relief, firefighting, medical evacuation, commercial delivery services, and civil transportation. [Ref.1:p.7]

Furthermore, as described by Pennsylvania Congressman Curt Weldon, in an interview with the researcher:

From the standpoint of our industrial base, its the first really new technology that looks like its going to be built completely in the U.S. Which I think is a major moral win for America, and why I labeled it America's airplane a few years ago. It was given the Collier Award as the

most significant breakthrough in technology. Its going to mean tens of thousands of manufacturing jobs, and is going to allow us to maintain the lead in the one area we have dominated the world, and that's aviation products... In a time where we're loosing our industrial base, and our manufacturing jobs are going offshore left and right, here's one thing that can serve as a remainder that America is still the leader in manufacturing. The tiltrotor could be an example of that. [Ref.3]

For quite some time, there has been an urgent need for the Marine Corps to replace its fleet of approximately 300 CH-46E Helicopters. This sense of urgency may be associated more with the aircraft's age and deteriorating condition, as opposed to changes in the threat or mission requirements. Though the aircraft's condition may now be the driving factor for finding an alternative, this is not the only reason [Ref.1].

The CH-46E's primary role is troop transport, and it satisfies the Marine Corps' medium lift requirement. Medium lift is a central aspect of the Marine Corps' assault support mission. Of critical concern to the Marine Corps, is how it will satisfy an increased assault support requirement, as part of a new and improved amphibious assault capability. This capability is to be the cornerstone of the Marine Corps' future contribution to the Navy's "Forward from the Sea" strategy. [Ref.1]

For nearly twenty years the Marine Corps has championed the notion that the tiltrotor is the solution to its Medium Lift Requirement (MLR). The MV-22 now represents the only version of this concept, currently nearing production. [Ref.1]

In the commercial market, the status of tiltrotor development is quite different.

#### **A. STATEMENT OF THE PROBLEM**

The commercial potential of the Tiltrotor is tremendous... This unique capability makes it a viable solution to many of the major problems facing

the industry today. [The Honorable Tom Lewis (R-Fl) Opening Statement Civil Tiltrotor Hearing July 17, 1990] [Ref.1:p.23]

Several years ago, the Japanese Minister of Trade visited the Bell Plant to observe the tiltrotor. Congressman Geren, in describing both the Japanese Minister's reactions and words, wrote:

He watched the aircraft take off; he watched it maneuver; he saw the many things that it was capable of doing. I am sure that he let his imagination run wild as he thought about the congestion problems and the transportation problems that they have in their country and he said flatly, 'If you build it, we'll buy it. If you don't build it, we will.' [Ref.1:p.5]

Similar to past revolutionary concepts, such as the first jet aircraft or the first rotorcraft, the tiltrotor may promise vastly new capabilities and potential. Still, as of 1996, in the civil arena, there has been no firm commitment to develop this unique technology.

### Why?

According to a industry base impact study concerning the effects of tiltrotor technology:

Transfer of technology between military and commercial applications is as old as human kind...The military has been responsible, directly and indirectly, for a vast number of important technological contributions to modern society. These contributions span a wide spectrum of economic activity from research and development to the implementation of finished products and systems...Finished products made for the military and subsequently adopted by commercial manufacturers run from such simple items as fasteners to sophisticated technologies such as computers and radar, and to such complex products and systems as rockets and other aerospace applications. [Ref.2:p.27]

From the previous statement one can see that the MV-22 may represent more than just the next leap in aviation technological advance. The Marine Corps' procurement

could be another example of a historical trend that has existed as long as the aviation industry. Civil applications of advanced aviation concepts have, to a large extent, been contingent upon the Government (particularly Defense) bearing the lion's share of development costs and risks associated with proving new technologies. [Ref.1]

It is the researcher's contention that civil tiltrotor (CTR) applications are likely to occur, only as a result of continued Defense development and procurement of the MV-22.

## **B. OBJECTIVE AND TENTATIVE HYPOTHESIS**

The main objective of this thesis research will be to validate or reject the researcher's tentative hypothesis. That hypothesis is that **CTR applications are following a historical trend, and that Defense development and procurement of the MV-22 Osprey is a prerequisite to commercial development of the tiltrotor.**

The following is the primary research question:

**Are potential CTR applications dependent on Defense development and procurement of the MV-22 Osprey, and if so, to what extent?**

The primary research question can be divided into a number of smaller subsidiary research questions to make the investigation more manageable. They are:

1. Is there an historical commercial aviation dependence on Defense aviation research and development efforts?
2. What are the historical barriers to commercial aviation innovation, and to what extent have these barriers been influenced by past Defense aviation development efforts?

3. Is there market potential for CTR applications, and if so, in what areas do these markets apply?
4. What are the barriers to commercial innovation of the tiltrotor concept?
5. Has previous Defense involvement in tiltrotor research and development (other than the MV-22), had any influence in overcoming the barriers associated with the CTR, and if so, to what extent?
6. Will Defense development efforts involving the MV-22 help influence any of the barriers associated with the CTR, and if so, to what extent?
7. Are there any other benefits that potential CTR applications are gaining, or likely to gain from Defense development and procurement of the MV-22?

### C. SCOPE

The focus of this research effort entails an examination of the following:

1. The historical relationship between Defense aviation development and commercial aviation innovation.
2. The history of tiltrotor research and development.
3. The market potential for civil applications of tiltrotor technology.
4. The current state of CTR research and development. This includes any considerations impacting on current and future CTR development.
5. How continued development and procurement of the MV-22 relates to the future potential of CTR applications. This includes potential CTR gains from technology transfer or other benefits.

There are a myriad of applications in which tiltrotor technology is envisioned to operate. An in-depth analysis of each one would be impractical given the available time and resources. Therefore, for the purposes of this research, the majority of applications

will be mentioned only briefly. However, it is necessary to provide clarification regarding the use of two terms that relate to all potential applications. This may have been accomplished best by Boeing's CTR Marketing head, Steve Barlage. In an interview, Barlage presented standard terminology used throughout the aviation industry to define potential tiltrotor markets. As Barlage described it:

The term civil refers to all tiltrotor applications other than military. Whereas commercial refers only to those applications involving for hire. The term commercial is therefore a subset of civil. Despite this distinction, the term civil is commonly misused and applied even when referring exclusively to commercial applications. [Ref.4]

For purposes of this thesis, unless otherwise clarified, both terms will refer to the short-haul commercial passenger market. Other markets will be identified, and briefly discussed in Chapter IV.

Additionally, the researcher feels compelled to clarify the use of two additional terms as they relate to the research material. First, the term technical **feasibility**, refers only to the technical capability of producing an aircraft that is representative of a particular concept. Second, the term economic **viability** refers to the practicality of employing and successfully sustaining operations, with due consideration given to the impact of economic factors.

#### **D. METHODOLOGY**

This thesis involves a qualitative research process. Having constructed a tentative hypothesis during thesis proposal formulation, analytic induction was used as an alternative

to field research to validate or reject the hypothesis. This thesis did not lend itself to observation. Two data collection alternatives were used.

The first method involved a comprehensive review of relevant literature. It involved obtaining documents through organizations such as the Naval Postgraduate School (NPS), the Defense Logistics Studies Information Exchange (DLSIE), Boeing Helicopters, Bell Helicopter Textron, the Federal Aviation Administration (FAA), the National Aeronautics and Space Administration (NASA), and the MV-22 Program Office.

Second, to the extent that adequate data collection and analysis could not be accomplished solely through literature or other sources, the researcher conducted personal interviews. These interviews include various experts or well versed authorities from across the spectrum of Government, Defense, and private industry.

#### **E. ORGANIZATION OF THE STUDY**

Chapter II provides background for the study, by examining the historical relationship between Defense aviation development and commercial aviation innovation. The historical barriers to commercial aviation innovation are identified and discussed. Finally, how those barriers have been influenced through Defense aviation efforts are highlighted.

Chapter III presents an overview of Defense research and development efforts, specifically involving tiltrotor technology. It recounts the history of vertical flight, and examines the genealogy of the tiltrotor concept. It also highlights the relationship between

four tiltrotor developmental prototypes, in establishing the technical feasibility and maturity of the tiltrotor concept.

Chapter IV assesses the overall market potential for civil and commercial applications of the tiltrotor concept. It examines previous market research conducted over the last ten year period. The chapter's focus is the identification and discussion of any barriers that inhibit commercial introduction of CTR applications.

Chapter V identifies and discusses any evidence of a dependence between Defense development of the MV-22, and commercial innovation of the tiltrotor concept. The chapter also addresses technology transfer, learning experience, and other benefits derived from Defense development of the Osprey.

Chapter VI draws conclusions and lessons learned based on the data and evidence collected. The chapter answers both the primary, and subsidiary research questions. It also provides an opportunity for the researcher to address lessons learned, and to make recommendations regarding areas warranting further research.

## **II. CIVIL AVIATION'S HISTORICAL DEPENDENCE ON DEFENSE AVIATION DEVELOPMENT**

Military aviation has a history of its own. But it has also served as contributor and precursor to some of the early innovation and evolution that has taken place in civil aviation. According to Miller and Sawers, some of the most significant aviation developments such as the jet aircraft and helicopter, first came to fruition in military aircraft designs. Furthermore, a large percentage of these advances have ultimately evolved, and been exploited through commercial and/or civil operational use. [Ref.5]

As Congressman Robert G. Torricelli pointed out in Congressional hearings, "virtually all major advances in aviation in this country have had a military technological precursor...that is unlikely to change in the near term." [Ref.1:p.1]

This chapter will examine the early relationship between Defense aviation development and civil aviation innovation. It begins with a discussion of the concept of technical innovation, and the elements that comprise it. This includes a look at the concept from both a general point of view, as well as from the unique perspective of the aviation industry. This requires examining the precursors to innovation, and its overriding economic underpinnings. Some of the more significant historical barriers to commercial aviation will then be identified and discussed. Next, how these barriers have been influenced, through Defense development and operational use, will be explored. Finally, some of the more revolutionary technologies that reflect this early dependence will be discussed.

## **A. CIVIL AVIATION INNOVATION; ITS PRECURSORS AND ECONOMIC UNDERPINNINGS**

There are many factors that influence the source of innovation. Eric von Hippel in his book entitled "The Sources of Innovation" argues that "variations in the sources of innovation are caused to a significant degree by variations in potential innovators' expectations of innovation-related profits." [Ref.6:p.6] However, to fully understand the nature of innovation, its origin and precursors must first be examined.

### **1. Invention, Development, and Innovation**

Miller and Sawers seem to provide one of the most clear and concise discussions of what invention, development, and innovation are:

Invention is the idea or the experiment that makes a new product or process possible, while development turns the first crude product into something that is commercially useable. Innovation is the exploitation of the developed invention. [Ref.5:p.5]

### **2. Who Instigates Civil Aviation Innovation?**

In regards to who specifically instigates innovation, Von Hippel helps clarify and correct a widely held misconception. He writes:

It has long been assumed that product innovations are typically developed by product manufacturers. Because this assumption deals with the basic matter of who the innovator is...it now appears that this basic assumption is often wrong...the sources of innovation vary greatly. In some fields innovation users develop most innovations. [Ref.6:p.3]

This is particularly relevant in the case of the aviation industry. In this context, the "user" refers to the military or the commercial airline operators, and not passengers

or flight crews. For commercial aviation it is unlikely that aircraft manufacturers like Boeing, Lockheed, or McDonell Douglas are the driving force behind aircraft innovation. Rather, it is United, Delta, or American. This contention is strongly supported by the aircraft manufacturers themselves. Take for example, the statement by Edward J. Renouard, Executive Vice President and General Manager of Boeing Helicopters, who in testimony before Congress emphatically stated that "we [Boeing] do not launch new aircraft programs, our customers do" [Ref.1:p.70]. It could be said then, that "Users" are the instigating or driving forces behind a majority of aviation technological innovations.

### **3. Why Do Users Innovate?**

Is commercial aviation innovation a result of spontaneous scientific discovery, invention, or available technical knowledge? Or is the innovation of aviation technology stimulated more by the business prosperity of the innovator, or growing market demand for a particular aircraft capability? "The traditional view is generally that discovery and invention are independent of economical factors in their incidence, but not in their application." [Ref.5:p.6] Available literature tends to endorse the idea that the origin of invention may be scientifically or technically based, but that without the additional influence of economic factors (i.e., the potential for profit), the commercial exploitation and application of that invention is unlikely to occur. [Ref.5]

The term exploitation as used by Miller and Sawers seems a choice description of innovation. Particularly, when used in the commercial context, and paired with the views of others on the subject. In Bela Gold's book entitled "Research, Technological Change,

and Economic Analysis, Gold writes: "Technological innovations are inherently attractive, especially in terms of the economic rewards which are widely considered to be overriding in business organizations." [Ref.7:p.1] Commercial aviation users invest and innovate as part of their overall strategic plan to remain competitive. The overriding economic rewards as a result of their investment, competitiveness, and successful exploitation are profits. [Ref.7] The manufacturer is therefore dependent upon the propensity of the commercial aircraft user to innovate. [Ref.5]

One expert's opinion concerning what has been discussed to this point is provided by F.M. Scherer, in his book entitled "Innovation and Growth." As Scherer sees it:

Although each of the functions appears to be a necessary condition for technological advance, it is possible that innovation, investment, and development are more sensitive to economic variables than invention is. Inventive acts of insight may follow from scientific curiosity and a fortuitous combination of chance factors without any direct stimulus from profit expectations...execution of the innovative, investment, and developmental functions depend much more directly than invention on these economic factors. [Ref.8:p.26]

## **B. CIVIL AVIATION INNOVATION; THE BARRIERS**

Literature on the history of commercial aviation makes reference to several major barriers effecting successful innovation. Somewhat vague and open to interpretation, the researcher has made the following generalized observations in regards to interpreting the historical literature.

First, there appears to be three major barriers that apply to both the fixed-wing airplane, as well as the helicopter. They are:

1. Public acceptance
2. Technical risks
3. Financial risks. [Refs.1, 2, 5 and 9]

There also appears to have been two additional barriers, that in the past, applied only to the helicopter. Furthermore, these barriers only applied when discussing the helicopter's potential use in the short-haul commercial passenger market. [Ref.2] They are:

1. The lack of a supporting infrastructure.
2. A systems problem.

This last barrier pertains to the lack of a consensus building coalition, capable of committing to a heliport network or "system" [Ref.2]. Market studies have eliminated the helicopter from consideration as a short-haul market contender [Ref.2]. Still, mention of these helicopter barriers is worthwhile, because of their relevance to future application of the CTR in this same market.

The five barriers are influenced and effected by many interrelated issues and considerations. So many, that Boorer, in his article on aspects of civil V/STOL aircraft, collectively described these issues as being comprised of many "permutations and combinations" [Ref.9:p.11-2]. Furthermore, Boorer felt there were far too many issues to discuss individually [Ref.9:p.11-2].

Still, it seems appropriate to discuss some of the more key issues. A discussion of some of the most relevant issues follows:

### **1. Public Acceptance**

There are issues involving the public's (passenger) perceptions that are quite unique to the aviation industry. Some should be examined in order to have an adequate understanding of how perceptions effect the public's acceptance of a new aviation concept.

Aviation travel has proven to be significantly safer than automobile travel. However as Miller and Sawers describe it:

Fear plays a larger role in keeping travelers away from airlines than from any other transport medium. This remains true even though the relative improvement in the safety of airline service, according to the measures usually presented, has been greater than for major surface transport media. [Ref.5:p.221]

This is supported by the statistics compiled by the Air Transport Association of America, and the National Safety Council over the last half century (Figure 1).

Despite the realities, the traveling public's perceptions concerning air travel safety are far more influential in determining their acceptance and demand, than is the statistical evidence. Furthermore, as described by Brigadier General Robert Magnus, Deputy Chief of Staff for Marine Aviation, "the public wants the industry to establish with a reasonable degree of certainty that an aircraft's not going to come apart in the air" [Ref.12].

Boeing Helicopter's Executive Vice President Edward Renouard believed that gaining the acceptance of a new aviation concept, is initially, perhaps the most difficult of the barriers to overcome. Because, according to Renouard, it "lacks the credibility of

experience" [Ref.1:p.93]. To overcome this barrier as Renouard put it "requires experience and demonstration" [Ref.1:p.92].

Sched

<u>Year</u>	<u>Airlines</u>	<u>Automobiles</u>	<u>Buses</u>	<u>Railroads</u>
-------------	-----------------	--------------------	--------------	------------------

1938	5.21	3.9	n/a	0.36
1946	1.26	2.5	0.19	0.18
1956	0.64	2.7	0.16	0.20
1964	0.14	2.4	0.13	0.05

From [Ref.10:p.32]

1983	0.01	0.98	0.05	0.04
1984	0.02	0.98	0.03	1.11
1985	0.07	0.96	0.04	0.03
1986	0.002	1.27	0.03	0.03
1987	0.07	1.22	0.03	0.13
1988	0.01	1.19	0.03	0.02
1989	0.04	1.12	0.04	0.06
1990	0.003	0.99	0.02	0.02
1991	0.03	0.91	0.02	0.06
1992	0.01	0.83	0.02	0.02
1993	0.01	0.82	0.01	0.42

From [Ref.11:p.122]

Figure 1. Comparative Transport Safety Records  
(Fatalities per 100 million passenger - miles)

## 2. Technical Risks

Lacking the benefit of experience and operational data, in the early stages of aviation, the technology was considered far too risky and unreliable. It was therefore difficult to convince potential operators to invest in commercial aviation. As a result, for years after the airplane's inception the commercial market remained a relatively small one.

[Ref.5:p.9] The commercial helicopter market remains small to this day [Ref.2].

Slow growth rates and a conservative approach to innovation, continue to be historic commercial aviation trends. According to the Civil Tiltrotor Development Advisory Committee (CTRDAC):

The speed and success with which new technologies and operational concepts can be introduced into transportation systems is strongly affected by the degree of innovation involved. [Ref.13:p.81]

Though operators may see potential in an advanced aircraft concept, that alone is not enough to get them to commit to it. Operators first need proof that within the capabilities of the aviation engineering community, the concept is technically feasible. It therefore becomes what General Magnus described as "a chicken and egg thing" [Ref.12]. Others, like Boeing's Renouard, have used this analogy to describe other aspects of tiltrotor risk, such as the lack of supporting infrastructure. The researcher believes that General Magnus is describing more what one might refer to as a Catch 22 scenario. Regardless, our interpretations of the dilemma are the same. That is: Should prospective operators be expected to commit resources to an aviation concept without that concept

having been proven first? Yet, how can that proof be gained without the resource commitment of some entity?

Furthermore, adding to the operator's cautiousness is that even when proven feasible, an aircraft can still fall short of production. Consider the views of General Magnus on the subject:

From an engineering standpoint, there's a lot of things the aviation industry has proven it can do. But if nobody else is willing to field the thing, then why would the commercial aviation industry [which is extraordinarily conservative] want to be the first to take the technical risks of fielding it? And the answer is that they wouldn't. [Ref.12]

According to Boeing's Renouard, "air carriers are very conservative about adopting new technologies because they can afford zero risk in either safety or dispatch reliability" [Ref.1:p.93].

This statement is representative of a basic tenant concerning the relationship between technical risk and innovation. As Scherer explains it:

It illustrates cogently a principle that has widespread application in the innovation of new products and processes: the concept of undertaking costly specific development projects only when these basic uncertainties have been sufficiently reduced. [Ref.8:p.5]

### **3. Financial Risks**

According to General Magnus, it all comes back to economics. As he explained it:

Proving an aviation concept technically feasible simply answers the question as to whether or not the technology can be built from an engineering standpoint. It does not concern itself with answering the question as to whether it can be built and operated for a price. [Ref.12]

For those who are willing to assume the financial risks associated with innovation, Joseph A. Schumpeter in his book entitled "Capitalism, Socialism, and Democracy" argues that:

Those who succeed at innovating are rewarded by having temporary monopoly control over what they have created. This control, in turn, is the lever that allows innovators to gain an enhanced position in the market and related temporary profits from their innovations. [Ref.14]

Schumpeter puts a positive spin on this temporary edge. Professor J.K. Galbraith saw it somewhat differently in his book "American Capitalism." He wrote:

Following development, imitators appear so quickly that a firm in a competitive situation gains only the fleeting rewards of a head start. [Ref.15:p.87]

Because of this situation, Galbraith points out that:

Only a firm large enough to afford the high cost of developing a modern invention is able to profit from its investment. Rising development costs, have made these rewards inadequate to encourage investment. [Ref.15:p.87]

This situation has grown so serious according to Renouard of Boeing that:

The principle cause for the apparent decline of the U.S. aviation industry is high (and growing) development costs. This record of the civil aircraft industry's declining ability to stay afloat in a long economic boom is alarming. It is particularly troubling in that,...there is no solution in sight. [Ref.1:p.96]

Peter Schwartz points out in his discussion on innovation and investment that "innovation is a gamblers game, and therefore cautious investment means slower growth" [Ref.16:p.193]. Despite this apparent cautiousness, as Scherer points out, "both invention

and innovation, along with investment, are necessary and complimentary functions in the advance of technology" [Ref.8:p.25]

#### **4. Lack of Supporting Infrastructure**

An aviation supporting infrastructure pertains to the framework of various organizations, facilities, and services required to support the operation of an aircraft. In the early years of fixed-wing innovation, infrastructure was not a major barrier. Aviation operations were so limited, as were the capabilities of the aircraft themselves, that there were few support requirements. [Ref.5]

This changed, and over the course of many years both a national and global aviation infrastructure evolved. The infrastructure emerged not so much a result of strategic planning, but more out of necessity. As aircraft advanced, so too did the need for the infrastructure to support it. As the infrastructure improved, so to did the potential for further aircraft innovations. The two inputs to the system responded to each other, and evolved together. [Ref.5]

What permitted such an evolutionary process to begin nearly a century ago was the relative simplicity of the flying machines, and the negligible demands they initially had for infrastructure. [Ref.5] It could not happen that way today. The capabilities of today's modern aircraft are beyond the imaginations of yesterday's innovators. With that added capability comes an increased burden on the support structure in order to fully realize those capabilities. [Ref.5]

Today we have a mature, national transportation system, in which one element can not flourish independently. The long term economic viability of a new innovation is dependent to a great extent, on the capabilities of the infrastructure to support it. [Ref.5] This barrier was realized with the attempted introduction of the helicopter into the short-haul commercial passenger market [Ref.2].

### **5. A Systems Problem**

What the conventional fixed-wing aircraft had in its favor, was that the aircraft and its infrastructure developed concurrently. In the case of the helicopter, the infrastructure required to support short-haul commercial passenger service did not develop. [Ref.2] In regards to obtaining the necessary structure and support mechanisms, we are confronted with what Boeing's Renouard referred to as "the chicken and egg situation." He also referred to it as "a systems problem" [Ref.1:p.94].

On the one hand, the costs associated with building a new infrastructure or modifying the existing one to accommodate future innovations would prove cost prohibitive. On the other hand, fielding potential advanced technologies may prove impossible without the support structure to do so. Investors are incapable of providing what Renouard refers to as "patient capital" [Ref.1:p.96]. Patient capital refers to long-term investment which is aimed at ensuring the long term economic viability of the new technology. It includes such initiatives as planning and constructing aerodromes and facilities, and instituting required changes to the Air Traffic Control System (ATCS). [Ref.1:p.96]

The total investment in infrastructure to accommodate the introduction of a new aircraft is according to Renouard:

Clearly beyond the control of industry. Federal effort will be needed in this chicken and egg situation. [Ref.1:p.94]

### **C. DEFENSE AVIATION'S CONTRIBUTION IN OVERCOMING THE COMMERCIAL BARRIERS**

Once early aviation pioneers achieved the first flyable prototypes, they turned to the war departments of the world to support the development of their inventions. It was also from the military that early manufacturers gained their first requests for aircraft production. [Ref. 5]

#### **1. Leadership in Research and Development**

The general unwillingness of private investors to take the lead in aviation technological development is not new. According to Miller and Sawers "the history of the airline industry predisposed it to lean on the governments" [Ref.5:p.2]. Most research and development efforts associated with radical leaps in aviation technology have been lead and funded by Government efforts [Ref.5].

Aircraft manufacturers have, in most cases, been unwilling to assume the full financial responsibilities associated with development, as well [Ref.17:p.50]. As explained in a Defense News article, aviation research and development has been comprised of just as many unsuccessful attempts, as successful innovations. Additionally, there have been aircraft that were proven technically feasible, yet not produced. For many reasons, including

competing priorities and limited resources, there is no guarantee that the Defense Department will pursue a technology any further. [Ref.17:p.50]

Aircraft manufacturers are keenly aware of this reality, and make their business decisions concerning development costs accordingly. As explained in that same Defense News article, "the Navy needs to take moves to reassure industry about its intentions to produce the systems industry develops" [Ref.17:p.50].

If past trends are indicative of things to come, "companies [manufacturers] will be unwilling to take big risks developing systems that the military may or may not buy" [Ref.17:p.50]. This is true according to the Defense News article because:

Industry needs to be reassured it can earn reasonable profits based not only on the systems it develops that go into procurement, but also on systems that do not move into procurement. [Ref.17:p.1]

Innovators and manufacturers are driven primarily by profit. An aircraft manufacturer's ultimate goal then, is to get an aircraft design to the production phase. The commercial operator ultimately wants to recoup their investment in the operating environment. Neither manufacturer, nor potential operators, are particularly interested in using their own finances to develop these aircraft. [Ref.5]

Manufacturers prefer their customers to help share the cost of developing aircraft, regardless of who the customer is. Commercial operators would prefer to exploit aviation technologies once developed and financed by someone else. [Ref.5]

Both manufacturers and commercial operators have long depended on the Defense Department to help overcome the technical and financial barriers to commercial aviation. The Government has accomplished this through its risk taking leadership, and its willingness to assume a great deal of the costs of research and developments. [Ref.5]

## **2. Providing Operational Experience**

During the introductory phase of an advanced aircraft design, the Defense Department inadvertently risks the lives of some of its personnel enroute to gaining valuable operational experience. This view is supported by Tom Archer, an FAA Rotorcraft Certification Directorate. In an interview with the researcher, Archer, a reserve military aviator felt that "it's always been politically less sensitive to kill a few military aviators in proving an aircraft, as opposed to killing members of the general public" [Ref.18].

Though more subtle in his delivery, Congressman Pete Geren, R-Texas, essentially holds a similar view. In an interview, Congressman Geren maintained that it is widely held that, "if you want to prove a technology, let the military break it first" [Ref.19].

Gaining operational experience is necessary to prove a technology's commercial potential. It provides evidence over time that any design deficiencies or "bugs" that were present during development, have been dealt with, and eliminated. Boeing's Renouard supports this idea as well. According to Renouard, "Bell-Boeing market surveys confirm that the user insists that such technologies be wrung-out by military operating experience" [Ref.1:p.93].

In addition to influencing the public acceptance and technical risk barriers, gaining operational experience can also help mitigate the financial risks. According to Bell's Horner, commercial carriers are interested in the experience gained by the military because "potential operators want validated reliability, maintenance, safety, environmental, and operating cost data" [Ref.1:p.93].

Some experts believe that overcoming the acceptance barrier was what ultimately paved the way for commercial aviation. [Ref.1 and 5] According to Miller and Sawers, by the end of World War I, "airlines were already being planned...based on optimistic assumptions." [Ref.5:p.12] Miller and Sawers further explain that these assumptions concerned the savings and reliability that could be derived from proven military aviation technology, as well "the number of travelers that would be prepared to fly" [Ref.5:p.12].

#### **D. CIVIL INNOVATION OF MILITARY AVIATION TECHNOLOGY**

Following World War I, most of the early airlines used converted military machines, and later derivatives of them. However at the time, only a few German machines, like the Junkers and Rohrbach, "pointed the way towards the truly commercial airplane of the future" [Ref.5:p.2].

For more than 20 years following World War I, airlines only got bigger, faster, more powerful, and able to fly for longer distances, with pressurized fuselages to allow higher flying. But the technology remained basically unchanged. [Ref. 5] In the following years, military development of three key technologies was eventually exploited

by the commercial aviation industry. Those technologies include the jet engine, the large jet aircraft, and the helicopter. [Refs. 2 and 5]

### **1. Government Contributes the Jet Engine**

In the late 1930s, preparations for World War II concentrated efforts on military aircraft. According to Miller and Sawers, it also helped push one of the most fundamental technological advances in design that the aviation world has ever seen; the jet engine. [Ref.5]

The jet engine came into military service about 15 years before it was established in the airlines. [Ref.5] According to a Department of Transportation (DOT) study "the most unequivocal gift that governments made to the aircraft industry was the jet engine." [Ref.2:p.39] Furthermore, according to the study, the J-57 engine "would not have been developed but for the complex interdependence of government and private sectors."

[Ref.2:p.38]

### **2. Evolution of the Commercial Airliner**

Through the 1940s and 1950s, at government expense and primarily for military use, technology involving both airframes and jet power plants were gradually improved. [Ref.5] These advances were most notably achieved in both the B-47 and B-52 bombers.

[Ref.2]

Early in the 1950s engines originally designed for the military were adapted into commercial aircraft. The first jetliner was the British de Havilland Comet I, flown in

1952. After two years of flying, four accidents related to structural integrity led to its termination. [Ref.2:p.38]

Boeing, having success in its military B-47 and B-52 designs, was initially unsuccessful in interesting airlines in a civilian jet transport. One of the key factors according to the DOT was the lack of experience in military jets. [Ref.2:p.39]

Boeing went forward with development of a large commercial prototype using its own resources. The prototype known as the 367-80, was the pre-production version of what later became the Boeing 707. The DOT study maintained that "the 367-80s aerodynamics plainly owed much to Boeing's prior experience with military jet airplanes." [Ref.2:p.39] It took advantage of the B-47's swept-back wings, and the J-57 engine utilized in the B-52. [Ref.2] Several months after the 367-80's first flight, Pan Am ordered twenty 707s, precipitating what the DOT study referred to as "a year-long jet-buying spree by the world's airlines" [Ref.2:p.40].

The subsequent history of commercial aviation is one of a growing market, and steady divergence from its early dependence on military technological advances. This is primarily true, because advances occurring since the 1950s have been more iterative in nature, as opposed to being considered revolutionary innovations. [Ref.2:p.30]

### **3. Evolution of the Commercial Helicopter**

Built with private funds, the Sikorsky VS-300 helicopter made its first flight in 1940. Within a year Sikorsky won a contract with the Army. Since that time, according

to the DOT study, "the military has been a primary force in the helicopter industry."

[Ref.2:p.31]

The commercial helicopter industry grew rapidly in response to military advances. The R-series helicopter helped prove the technology during the later years of World War II. The S-51 became the first civil derivative, and was a direct spinoff of the R-5 military helicopter. [Ref.2]

The Air Force awarded Sikorsky an additional military contract in 1949 to build the H-19. This ten passenger aircraft was eventually ordered by all the Services for use in Korea. It too had a direct civil spinoff certified as the S-55 in 1952. [Ref.2]

The HR2S built for the Marine Corps was one of the largest of the early helicopters, capable of seating 26 passengers. Its civil spinoff, the S-56 was relatively unsuccessful in finding a market. [Ref.2]

The last Sikorsky product built for the military in the 1950s was the HSS-2. Built for the Navy, it seated 25. According to the DOT study, its civil variant, the S-61 was certified "after more than 1400 hours of test and demonstration flights as a Navy helicopter." [Ref.2:p.34]

According to the DOT study, "commercial versions of military models often needed few modifications beyond interior improvements." [Ref.2:p.34] Additionally, military contracts provided financial safety nets, such that manufacturers could risk venturing into the civil market. [Ref.2]

According to the DOT study, civil helicopter use owes much of its success in making inroads over the traditional public acceptance barrier, to military operational experience during the Korean War. [Ref.2:p.35]

However, while helicopters have entered the civil sector, the market for commercial use of the helicopter has never materialized to the industry's expectations.

[Ref.2] A late 1960's study to investigate the potential use of helicopters in the short-haul passenger market identified why. Two key barriers were identified. First, the industry was unable to rally the required support to develop a intra-city helicopter infrastructure. Second, the industry concluded that :

The costs and benefits of intercity helicopter service were impossible for any one party to internalize - not the airlines nor the cities nor the Federal Government - that could justify the substantial expenditures needed up front to implement such a service. [Ref.20]

Very similar to the commercial airline industry, beginning in the 1960's, military and commercial helicopter technologies began taking on their own unique requirements and characteristics. As an example of this, consider that in the 1970s "military helicopters cost on average more than three times as much as commercial helicopters." [Ref.2:p.37] Though their unique market demands may be causing divergence between the military and civil helicopter industries, John F. Ward in his article on the future of rotorcraft makes a point worth considering. Ward points out that forecasts of future helicopter market penetration show a declining trend. He goes on to argue, however, that in the future, as in the past, military rotorcraft programs will directly support and influence future civil

developments. Ward summed up his optimistic outlook by emphasizing that the military development of new capabilities "has been the single most important catalyst in the development of the civil rotorcraft industry." [Ref.21:p.235]

Finally, supporting Ward's observation on market trends, consideration of the helicopter in the short-haul passenger market was abandoned in the early 1980's. A further discussion of this subject will be presented in Chapter IV.

#### **E. SUMMARY**

This chapter has provided background concerning the civil aviation industry's dependence on Defense development of advanced aviation technologies. The concept of technical innovation, particularly how it relates to commercial aviation was briefly described. Five key barriers to commercial aviation innovation were identified and discussed. Next, a discussion of how historically, the Defense Department has contributed in overcoming these barriers was provided. Finally, specific examples of military aviation technologies and their commercial derivatives were identified.

The next chapter will describe the history of Defense research and development specifically involving tiltrotor aircraft.



### **III. DEVELOPMENT AND EVOLUTION OF THE TILTROTOR**

This chapter introduces the tiltrotor concept; a member of the Vertical/Short Takeoff and Landing (V/STOL) category of aircraft. It explores the tiltrotor's genealogy, and its relationship with other, early attempts at achieving vertical flight.

It chronicles past research and development efforts specific to the tiltrotor concept, and in particular, the role Defense has played in them. A main purpose of these efforts is to highlight a continuing link between the DOD's current undertaking, the MV-22 Osprey, and its previous tiltrotor R&D efforts.

Finally, the research will examine whether previous Defense involvement in tiltrotor R&D has helped satisfy or overcome any of the historical barriers to commercial aviation innovation.

#### **A. OVERVIEW OF APPLICABLE TERMS**

It is necessary to clarify the use of three terms pertaining to aviation concepts, other than the Conventional Takeoff and Landing (CTOL) airplane.

1. VTOL - Vertical Takeoff and Landing
2. STOL - Short Takeoff and Landing
3. V/STOL - Vertical/Short Takeoff and Landing

According to David L. Kohlman in his book entitled *Introduction To V/STOL Airplanes*, a VTOL aircraft "must be able to takeoff, hover, and land with zero airspeed."

[Ref.22:p.3] The conventional helicopter is what immediately comes to mind. However others, like the tiltrotor and AV-8 Harrier, though not exclusively VTOL aircraft, are both VTOL capable.

The term STOL is somewhat more ambiguous. It cannot be defined simply in terms of its takeoff and landing distance. Kohlman states that:

STOL aircraft are identified not merely by the required field length, but by the field length in relation to weight, cruise speed, and wing loading. No one parameter is sufficient for an adequate definition of STOL performance. [Ref.22:p.4]

The old "autogiros," which lacked the ability to hover, are STOL examples. The Cessna 152, despite the fact that it may require no more takeoff roll than the Harrier, does not qualify as a STOL aircraft [Ref.22]. Once again, the Harrier, though not exclusively a STOL aircraft, typically operates in the STOL configuration. This is so for a several reasons, two of which pertain to this discussion.

First, because of mission duration and the fuel inefficiency of the Harrier's vertical thrust producing system, the mission pilot may have to avoid the pure VTOL mode whenever possible [Ref.22]. Second, the Harrier's ability to hover is highly dependent on takeoff weight and environmental conditions.

Kohlman defines a V/STOL aircraft as "one that can both hover in a VTOL mode or takeoff and land in the STOL mode." [Ref.22:p.5] A V/STOL aircraft must be able to accomplish both VTOL and STOL, as opposed to just one or the other, but owes its lineage to both categories.

Still, further clarification may be useful. For example, some might point out that the conventional helicopter (even the skid configured) can operate in the STOL mode, such as when executing a "sliding" takeoff or landing. They could argue then, that the helicopter satisfies the requirement for classification as a V/STOL aircraft. But as John Paul Campbell points out in his book entitled "Vertical Takeoff And Landing Aircraft":

The V/STOL transport is a machine that would be designed with enough power to hover or takeoff and land vertically when ever necessary, but in most operations it would probably use short takeoff and landing runs for improved economy, better handling qualities, and greater safety in event of engine failure. [Ref.23:p.184]

The helicopter would not appear to fit Campbell's description of a V/STOL aircraft. Further support for this lack of fit is provided by John J. Schneider in his article entitled *Rotary Wing V/STOL*. According to Schneider, although conventional helicopters may be made to loosely fit the definition of V/STOL, and sometimes are, they are generally excluded. They are more appropriately categorized exclusively as VTOL aircraft. [Ref.24:p.172]

In practice according to Kohlman, V/STOL aircraft are capable of much higher speeds, and have more of the qualities of an airplane. "Cruise performance comparable to conventional aircraft must also be possible." [Ref.22:p.5]

Though substantially unique in comparison to one another, both the Harrier and tiltrotor aircraft qualify as V/STOL aircraft.

## **B. THE BEGINNINGS OF VERTICAL FLIGHT**

Early development of the fixed wing airplane culminated with the well known success of Orville and Wilbur Wright on December 17, 1903. As presented in Chapter II, it was followed by periodic revolutionary advances due primarily to the developmental initiatives of the military. [Refs.2 and 5]

Most people are under the perception that it took years longer to achieve vertical flight. But as Hal Hellman in his book entitled "Helicopters And Other VTOLS" points out:

The first flights of a full-scale vertical rising aircraft came only a few years after the Wright brothers flight. In 1907, two different machines made that first painful step. [Ref.25:p.31]

Hellman was making reference to two French "helicopter-like" prototypes that successfully achieved hover flight for short periods of time. As in many early rotorcraft experiments, both remained tethered, because they were otherwise uncontrollable. [Ref.25:p.31]

Surprisingly, the earliest visionaries actually thought first in terms of vertical takeoff and landing, as opposed to conventional flight. As Hellman described man's aviation beginnings:

He watched the birds, nature's most magnificent fliers, for some clues. And what did he see? Most of them seemed to be able to rise vertically and to land in the same manner. It apparently never occurred to man to class himself with the larger birds who cannot accomplish VTOL. As a result many of his early attempts were based on flapping flight from a standing position. [Ref.25:p.25]

According to Hellman, because man's early aviation pursuits focused on the complexities and requirements of vertical takeoff and landing (VTOL), coupled with technological limitations of the period, "the ungainly craft called orintheopters (literally bird wings) were doomed to failure." [Ref.25:p.26] Hellman felt the early visionaries erred in not trying to pursue the use of fixed wing concepts first, or "emulate the gliding flight of the larger ones [birds]." [Ref.24:p.26] The difficulties he eluded to were a combination of two factors; one technical, and one aerodynamic. These factors pertained primarily to the limited power generation of available propulsion systems (engines), coupled with the increased lift requirements of vertical flight as opposed to conventional flight. [Ref.23] Both will be discussed in further detail later. Hellman saw an additional flaw in the orintheopter concept as rooted in the failure to separate the lifting surfaces from the propulsion system [Ref.25:p.26].

The "Chinese top" (actually a toy) dating from 400 B.C., consisted of a short stick with at least two feathers at the top serving as rotors. As Campbell explained "when the stick was spun between the hands and released, the toy would rise vertically like a helicopter, then descend as the spinning slowed." [Ref.23:p.8] This design embodied separation of the lifting surfaces (rotors), and propulsion system (hands) that Hellman described as necessary; however, it did not employ fixed wing concepts. Still many, like Campbell, believed the Chinese top, was to some degree, a successful beginning for the VTOL concept:

The principle of vertical takeoff and landing is certainly not a recent discovery. The Chinese are credited with the first development in this field over 2,000 years ago. [Ref.23:p.8]

There are no recorded additional designs in the VTOL category until Leonardo da Vinci's "aerial screw" came about in 1483 [Ref.23:p.8]. Da Vinci's design however, was never actually attempted.

During the nineteenth century, aviation inventors designed a variety of both vertical lift aircraft and winged airplanes. In 1843, Sir George Cayley of England designed his "aerial carriage" that had both rotors for hovering and propellers for cruise flight [Ref.23:p.8]. Though Hellman saw the V/TOL concept as the wrong way to initially pursue successful flight, he credits Cayley's VTOL design with being the first of any, to incorporate the separation of lifting and propulsion systems. "His idea history has shown, to be correct." [Ref.25:p.26]

Though there were earlier VTOL designs (conceptually) like the ornithopter and pure helicopter, Campbell believed Cayley's conceptual design was probably the earliest precursor to the V/STOL category. [Ref.23:p.13] Still, it did not incorporate fixed wing concepts. However, "the idea was remarkably modern in concept." [Ref.25:p.30]

### **C. THE V/STOL CATEGORY**

The category of aircraft known as V/STOL encompasses a broad range of unique applications. Along with them, come a diverse range of engineering complexity. V/STOL research and development has produced an amazing variety of configurations because as Kohlman felt, "there are so many possible solutions to the same problems." [Ref.22:p.3]

Campbell describes V/STOL aircraft as differing from the conventional airplane in two essential respects. They are the power required to hover as opposed to forward or cruise flight, and problems associated with stability and control. [Ref.23:p.24] Both differences relate to aerodynamic characteristics associated solely with vertical flight.

First, in regards to the power required, Campbell states that:

Thrust like weight, is measured in pounds. Conventional aircraft have values of thrust at takeoff that are only 30 to 40 per cent of the total weight being lifted. They are thus said to have thrust-to-weight ratios of about one third. [Ref.23:p.21]

The thrust-to-weight ratio in the vertical lifting mode must exceed the operating weight by some margin. As described by Barnes W. McCormack in his book "Aerodynamics of V/STOL Flight," "the development of static thrust to gross weight ratios must be greater than one." [Ref.26:p.1]

Schneider felt that during early attempts to develop VTOL capable designs, the inherent power limitations of then, state-of-the-art powerplants, was the greatest obstacle. In fact, Schneider believed that overcoming the thrust requirement, three to ten times that of a typical airplane, was the factor that delayed the development of the helicopter and the V/STOL aircraft by some thirty to forty years. [Ref.24:p.172]

Second, as described by Seth B. Anderson in his article on V/STOL aircraft technology, the craft must be capable of controlling pitch, roll, and yaw without the benefits of aerodynamic forces as a result of its speed, "until sufficient forward velocity is obtained." [Ref.27:p.9-4]

As propulsion systems evolved, the search for methods to convert horsepower to vertical thrust or VTOL, led to use of four vertical thrust producing systems. Though the exact terminology used to describe these systems may differ slightly, they generally consist of:

1. Rotors
2. Propellers
3. Ducted Fans
4. Turbofan/Turbojet [Ref.22, 23 and 25]

Both the thrust and efficiency generated by one horsepower, decreases in proportion to the size of the thrust generator or disc area. This varies from the rotors being the highest, progressively lower to propellers, ducted fans, and turbofans/turbojets.

In order to produce an equivalent amount of thrust, the power output (horsepower) and "disc loading" on each of the four systems must increase. Disk loading is essentially the thrust being produced, divided by the disk area for rotors and propellers, or the exit area for ducted fans and turbofans/turbojets. Disc loading on each of the four systems increases, moving progressively from rotors toward the turbofan/turbojet. [Ref.23:p.20]

For each of these VTOL systems, there are four technologies for converting the system from the vertical thrusting mode to the horizontal cruising flight mode, or achieving what is known as "conversion." [Ref.24:p.106] The four conversion technologies are comprised of:

1. Tilting Aircraft
2. Tilting Thrust
3. Vectored Thrust
4. Separate (Dual) Thrust [Ref.22, 23, 24]

There are numerous subtle variations on these combinations. Kohlman however, credits Campbell with devising a four by four matrix that identify 16 generally excepted configurations. [Ref.22:p.8]

The simplest method of conversion or redirection of the thrust vector is that of tilting the aircraft, a method typically used in the conventional helicopter or pure VTOL. A modest 5 to 10 degrees of tilting provides the necessary redirection of the thrust. [Ref.23:p.48-50]

Rather than tilting the aircraft, others have tilted only the thrusting system. Employing rotors in this configuration are tiltrotor prototypes like the XV-3, the XV-15, the MV-22, and proposed CTR variants. This concept tilts only the rotors, usually on the wingtips. The tiltwing tilts the entire wing and propellers. Tilting ducted fans and turbofans are similar in concept. [Ref.25:p.108]

Another approach to thrust tilting is the vectored thrust or thrust deflection method. Wing flaps, vane cascades, or nozzle-swiveling systems change the thrust vector 90 degrees or more. [Ref.23:p.52] The AV-8 Harrier employs swiveling nozzles.

Finally, the use of separate thrusters have a long history, involving many attempts at developmental prototypes. They are typified by the compound helicopter such as the Fairey Rotodyne, wherein rotors are used for vertical lift, while thrust in cruise flight is provided by wing mounted propellers or fans. [Ref.23:p.52-53]

"Performance of V/STOLs generally follows the trend of disc loading--the higher the disc loading, the higher the speed and range capability." [Ref.24:p.173-174] Therefore, in cruise flight, helicopters and rotor type V/STOLs have poorer efficiency than ducted fans or turbofans/turbojets [Ref.27:p.9-2].

Conversely, in a hover or low speed profile, the relative hover time available and fuel efficiency decrease with higher disc loading [Ref.24:p.174]. "On this basis, of course, rotors have the greatest hovering efficiency and turbojets have the least." [Ref.23:p.22]

As in most concept developments, there are tradeoffs to be considered in selecting an appropriate V/STOL design to satisfy a specific requirement. However, according to Anderson, "an example of a good compromise in this regard is the tiltrotor concept, which has good rotor efficiency in hover and reasonably good propulsive efficiency in cruise." [Ref.27:p.9-2]

#### **D. PRECURSORS TO THE TILTROTOR**

Using rotors to achieve higher thrust-to-weight ratios at lower disc loading and power requirements, the thrust barrier was overcome and VTOL was proven technically feasible in 1907 [Ref.25:p.99]. However, due primarily to problems in control according

to Campbell, vertical flight did not really become practical until the early 1930s [Ref.23:p.12]. Furthermore, because the jet engine had not yet materialized, developers were limited to thrust generators of the rotor and prop variety. [Ref.25:p.99]

By using large rotors which moved large masses of air relatively slowly the helicopter builders of the 1930s and 1940s were able to get their aircraft up into the air with the engines that were in existence. [Ref.25:p.99]

Igor Sikorsky is well known for his success in developing pure VTOL technology through helicopter design. However V/STOL designs combining fixed wing cruise capability with VTOL capability came later.

It is impossible to discuss the tiltrotor concept without addressing the Baynes Heliplane. A British aircraft that was patented in 1937 but never built because of World War II, it was described by Georgia Tech's McKeithan as "the first conceptual tiltrotor design." [Ref.1:p.108] Powered by two gas-generator turbines in the fuselage, they were to supply high-pressure gases through a pipe in the wing, to turbines in the wing nacelles. [Ref.24:p.174-175] The Heliplane had a striking resemblance to the modern day tiltrotor and was the first V/STOL design to incorporate the advantages of fixed wing aerodynamics. There were earlier STOL designs that took advantage of fixed wing capabilities, but these aircraft lacked the capability to hover. Still, despite the Heliplane's advanced design, a true tiltrotor had not yet been built. [Ref.24]

The Germans of the early 1940s exerted a great deal of influence on later V/STOL and tiltrotor development. Henrich Focke created several designs, starting with the Fa-61

lateral twin helicopter to perhaps his most interesting one, the Fa-269. The Fa-269 was a true tiltrotor design, but of the "pusher" variety. As was the case in most conceptual designs, very little developmental work was actually accomplished on the Fa-269. [Ref.24:p.176-177]

W. Laurence LePage, primarily associated with helicopter development, was in competition with Sikorsky for a U.S. Army VTOL contract in the late 1930s. LePage later suggested a tiltrotor based on his earlier XR-1 tandem rotor helicopter design.

The proposed design consisted of a conventional airplane fuselage and wings, with a rotor mounted at each wingtip...As the aircraft accelerated, however, the rotors could be tilted to operate as propellers. [Ref.24:p.177]

Again, the LePage design was never developed.

Following Sikorsky's success with the VS-300 helicopter and World War II, helicopter development continued to make much more progress than the V/STOL concept. As a result, according to Schneider, efforts involving the two technologies began to become quite distinct. [Ref.24:p.177]

#### **E. PROVING THE TILTROTOR TECHNICALLY FEASIBLE**

Helicopter development, primarily associated with the military, was now well underway. The first tangible progress in V/STOL development followed several years later, and was centered around tiltrotor technology.

##### **1. The Transcendental Model 1-G**

Robert Lichten linked up with an aero engineer by the name of Mario Guerrieri. Together they formed Transcendental Aircraft in 1945 and began development of the

Model 1-G. This was a single place tiltrotor using rotors approximately 17 feet in diameter, and having a gross weight of 1,750 pounds. [Ref.24:p.177] According to Campbell, "most of this work was done under joint Army-Air Force sponsorship" [Ref.23:p.73]. The first ground test runs were plagued by dynamic rotor and wing problems, but after extensive engineering effort the aircraft first achieved free flight on July 6, 1954. During the following year, over 120 flights were flown, and 23 flight hours accumulated. [Ref.24:p.177] The Model 1-G's achievements included 115 miles per hour in forward flight, with the rotors tilted to a position 70 degrees forward of the horizontal, and the lift produced by the wings supporting 90 percent of the aircraft's weight. [Ref.23:p.73]

The 1-G's success came to an end however, when it was lost in a crash while transiting the Delaware River. The accident was not related to tiltrotor technology. Rather, "the friction lock on the collective slipped and the aircraft went into a steep dive." [Ref.24:p.177] Although a larger Model 2 variant was eventually attempted, the contract's schedule and competitiveness had fallen behind that of the XV-3 currently under development by Bell. [Ref.24:p.177] Work on the Transcendental Model 2 was ultimately canceled. Lichten ended his association with Guerri and moved on to head up the tiltrotor program at Bell. [Ref.24:p.177]

## **2. The Bell XV-3**

The Bell XV-3 proposal was a continuation of the Guerri-Lichten tiltrotor design. [Ref.24:p.178] It was selected by the Army and Air Force for prototype

development as part of an industry-wide competition to explore the possibility of pursuing a new concept for observation and reconnaissance. More important, it "was also intended to provide design and test data for the development of larger, higher performance machines of this type." [Ref.23:p.73]

The first XV-3 was built in 1955. After about 2 months of hover tests and attempts to convert from the hover mode to forward flight, a "mechanical dynamic rotor instability or rotor weave" [Ref.27:p.9-7], resulted in a crash and loss of the aircraft. Following critical analysis of the cause of the accident, and a decision to build and test a second prototype, the modified XV-3 made its first complete conversion from the helicopter mode to cruise flight on December 17, 1958. [Ref.24:p.180] Rotor & Wing Magazine reported that "this was the world's first aircraft to convert from vertical to horizontal flight [fully] by rotating its props." [Ref.28:p.6]

During the next seven years, further testing established the tiltrotor concept as a technically feasible advanced aviation alternative. As described by Boeing's former Manager of V/STOL Technology, K.B. Gilmore:

The feasibility of the tiltrotor concept was demonstrated in the late 1950s by the Bell XV-3. This was basically a testbed aircraft and while it successfully performed its purpose of substantiating feasibility, it also pointed out some fundamental technical problems of the tiltrotor configuration, especially in the dynamics area. [Ref.29:p.19-1]

One of the "fundamental technical problems" that Gilmore failed to elaborate on was the phenomenon described earlier as "rotor weave." An additional technical problem specific

to the tiltrotor according to K.G. Wernicke, a Bell Engineer, is related to "the loss of vertical lift that the tiltrotor sustains due to the wing blocking some of the slipstream of the rotors." [Ref.30:p.3] Despite the inherent technical problems, as described by Rotor Magazine in 1992, the tiltrotor prototype had served its purpose, in that "the XV-3 was declared airworthy." [Ref.31:p.50] In 1966 the XV-3 was retired after accumulating 125 flight hours and 110 conversions, during the course of 270 total flights. [Ref.31:p.50]

Tiltrotor technology was ready for the next progressive leap in its evolution; a tiltrotor demonstration program. The XV-3 would prove particularly advantageous in preparing for that eventuality. As Rotor Magazine reported the event: "Following Phase II testing, the airframe was moved to NASA to finalize airframe configurations, and to use the XV-3 for future tiltrotor designs." [Ref.31:p.50]

#### **F. DEMONSTRATING TILTROTOR TECHNOLOGY: THE BELL XV-15**

So now that we have this technology (the XV-3), what are we going to do with it?..The risk involved in introducing any new aircraft...is now so high...the probability that the tiltrotor could be developed in one shot...from today's state of technology is very poor. If the technology we have developed is ever going to be applied to an operational aircraft, an intermediate flight step of a demonstrator aircraft or proof-of-concept vehicle which could be developed for a far more modest expenditure than a true operational prototype appears absolutely necessary. This aircraft must demonstrate far more than the feasibility aimed at in the XV-3...It must provide an honest flight demonstration that all the technology is in fact at hand and it must substantiate the predicted benefits of the configuration. [Ref.29:p.19-4]

Boeing's Gilmore presented his opinion several years before work was initiated on the Bell XV-15. However, it was a direct result of this perceived need by he and others,

that research involving tiltrotor technology took the course that it did after completion of the XV-3 program in 1966.

During the next five years research was predominantly a joint effort between Bell, Boeing, NASA, the Army, and the Air Force. Most of the emphasis was focused on improving the dynamics, and identifying and reducing the instabilities discovered during XV-3 flight testing. During this same time frame a number of studies were conducted at the request of NASA to explore and evaluate the potential of the tiltrotor concept in several commercial applications. [Ref.24:p.181-182]

As a result of the work completed on the XV-3, the Army and NASA were ready by 1972 to award a contract for development of a tiltrotor technology demonstrator aircraft. After design competition between both Bell and Boeing, Bell was selected to design and manufacture what was to become the Bell Model 300. [Ref.24:p.182]

Subsequent improvements over the initial configuration were so extensive that Bell elected to redesignate the aircraft as the Model 301, and later the XV-15. [Ref.28:p.6] Engineering design was completed in March of 1975, and subsequent assembly of the first of two prototypes was accomplished between October of 1975 and May of 1976. [Ref.24:p.182-183]

The XV-15 accomplished its first free hover on 3 May 1977. Later that same month, the aircraft underwent limited flight envelope testing of approximately three hours duration. The first in-flight partial conversion from 90 degrees (hover mode) to 5 degrees

forward took place on 5 May 1979. A graduated conversion schedule culminated with a full conversion being achieved on 24 July of that same year. [Ref.24:p.183-184]

Schneider described the full conversion as a momentous occasion, and one of great importance in advancing the tiltrotor concept. Also, the evolution had given those involved in the program enough confidence "to approve a fairly rapid exploration of the XV-15's remaining flight envelope." [Ref.24:p.185]

Cruise speeds of 300 knots and altitudes up to 21,000 feet were achieved in less than a year's time. The results supported a high degree of confidence in the safety and reliability of the prototype. More significant, according to Schneider, was the growing confidence on the part of those involved in the program that the XV-15 prototype design could successfully demonstrate the overall capability and versatility of tiltrotor technology.

[Ref.24:p.186-187]

The XV-15 represented a design that could move the tiltrotor concept closer toward eventual commercial innovation. This was the strategic role the XV-15 was envisioned and designed to fill. According to a Bell brochure,

The XV-15 tiltrotor aircraft demonstrates the executive transport application of tiltrotor technology...The XV-15 was developed under a NASA/Army/Bell research program as a tiltrotor concept demonstrator.  
[Ref.32]

Technology demonstration is not new, nor unique in its application to the XV-15. As described by Bud Laughlin, Senior VP for Loral Vought, "technology demonstration

is used to influence not only the customers, but the decision makers as well; particularly those who control the money." [Ref.33]

The notion that the XV-15 was developed as a "link" in the tiltrotor evolutionary process and not developed for operational use is indirectly confirmed in the findings of a 1994 MV-22 Independent Risk Assessment (IRA) Team. When commenting on the adequacy of MV-22 structural design issues the report stated that "other aeroelastic phenomena are being addressed for the first time in this, the first tiltrotor aircraft [MV-22] intended for operational usage" [Ref.34:p.3].

Through various marketing techniques and well orchestrated exposure, the XV-15 contributed to gaining both operator and public acceptance. For example, a "guest-pilot program" was initiated in 1981 to familiarize high-level military pilots and selected civilian pilots with the unique capabilities of the Bell XV-15 tiltrotor. [Ref.24:p.187]

Each flight by a guest pilot consisted of a brief demonstration of helicopter, conversion, and airplane modes...The guest pilot then took the controls and flew the aircraft. [Ref.24:p.187]

Another phase of the demonstration effort took place in March 1982. An east coast demonstration tour was arranged for a cross-section of operational, technical, and decision making personnel. The tour "included seven flight demonstrations at six different locations in eight days." [Ref.24:p.187]

As a result of emerging military requirements, and the capabilities demonstrated by the XV-15, the Defense Department was ready to explore tiltrotor technology for

military applications [Ref.24:p.190]. Additionally, it had long term implications for the possibility of commercial innovation of the tiltrotor concept. In fact, "Bell has taken the XV-15 on demonstration tours, even to New York City to allow commercial operators a glimpse of tiltrotor versatility." [Ref.28:p.7]

The Bell XV-15 had built on what the Transcendental Model 1-G and Bell XV-3 had started over twenty years prior. It had reinforced and solidified the technical feasibility of the tiltrotor concept. [Ref.28:p.6]

More significant was the contribution its guest pilot and technology demonstration programs had. Through dozens of individual and group flight demonstrations, culminating with a landing at the Capital on 25 April 1992, the XV-15 had served as the medium through which public acceptance of the tiltrotor concept could be gained.

#### **G. THE MARINE CORPS' SEARCH FOR AN AIRCRAFT**

Following World War II, the Marine Corps began exploring the possibility of employing V/STOL technology as part of their amphibious assault doctrine. Beginning in 1946, Marine Helicopter Squadron One (HMX-1) began to develop the vertical envelopment concept. Using HRP-1 helicopters, externally hung howitzers and supplies, as well as assault troops were delivered from ship to shore. With the addition of the HRP-2, the Marines were able to prove that the employment of helicopters in large numbers was not only feasible, but desirable and advantageous. [Ref.24:p.190]

Eventually the Navy developed dedicated helicopter assault ships to support this doctrinal change. The Marine Corps fielded the Boeing CH-46 helicopter in the mid-

1960s specifically to satisfy the troop transport requirement. Unbeknownst to the Marines at the time, the CH-46 would remain their mainstay troop transport for over thirty years. [Ref.24:p.190]

The Corps first explored a long term follow-on to the CH-46 as far back as 1968 during the Medium Assault Study. The potential of V/STOL aircraft (other than rotary-wing) to fill this requirements void once vacated by the CH-46, was vigorously studied under programs such as the Medium V/STOL Study. Tiltrotor technology, the advancing blade concept, even tilt fans had been explored. The other services had their evolving requirements as well. [Ref.24:p.190]

Around this same time, work had begun on the Bell XV-15 by the Bell-NASA-Army team. As a result of XV-15 development and its tiltrotor technology demonstration program, the Joint Vertical Lift Aircraft (JVX) Program was launched. [Ref.24:p.190]

The JVX program did not survive in its original form, and was later re-designated as the Joint Multi-mission Vertical Lift Aircraft or JVMX. Through the Defense acquisition process, the MV-22 Osprey was determined to be the best solution for that joint requirement. [Ref.35]

The JVMX program, and therefore the MV-22, is an outgrowth of the work done on both the XV-3 and XV-15. As explained in the CTR Industrial Base Impact Study,

The V-22 program is based on tested technology...The DOD sponsored research and development began with the Bell-designed XV-3 in the mid 1950s. The XV-15 program, jointly sponsored by the Army, Navy, and NASA conclusively confirmed the validity of the tiltrotor concept in the 1970s. XV-15 aircraft have logged over 600 hours of flight time and have

demonstrated the suitability of the tiltrotor for military missions. The V-22 production program is the logical development of these endeavors and the culmination of 30 years of tiltrotor research and development by the U.S. Government and American industry. [Ref.2:p.47]

This quote is somewhat dated. However, the main point is timeless. A link between the JV MX and previous Defense involvement in tiltrotor development is acknowledged.

This relationship is also supported by some entities charged with evaluating the health of the MV-22 program. Nora Slatkin, the former Navy Acquisition Executive, assembled an MV-22 Independent Risk Assessment (IRA) Team several years ago. Their goal was to assess Engineering and Manufacturing Development (EMD) issues impacting on two intermediate program milestones. In reporting the results of their assessment in August of 1994 the team:

Found it necessary to go beyond the immediate bounds of the EMD program. It is useful, for example, to consider the EMD as Phase IV of a weapon system acquisition program:

Phase 1: XV-15  
Phase 2: FSD  
Phase 3: Interregnum  
Phase 4: EMD [Ref.34:p.8]

The IRA Team's comments underscore the contributions the XV-15 technology demonstration program made in establishing the foundation on which the V-22 program is built.

## H. THE BELL-BOEING MV-22 OSPREY

According to the Joint Services Operational Requirement (JSOR), the MV-22 will provide the joint services with a multi-engine, dual-piloted, self-deployable, medium lift, vertical takeoff and landing (VTOL) aircraft to perform various missions for the year 2001 and beyond [Ref.35].

In December 1981, the Department of Defense formally began the MV-22 procurement process, when it directed the Concept Exploration (CE) of a multi-service, advance vertical lift aircraft. In June 1982, the services signed a Memorandum of Understanding (MOU) on the JVMX, designating the Army as the executive service. [Ref.36]

In December 1982, a Milestone I Defense Systems Acquisition Review Council (DSARC) review was held, rendering a favorable report on the JVMX program. This was followed by a Secretary of Defense Decision Memorandum approving the JVMX acquisition strategy, and requesting competitive proposals for development. [Ref.36]

By May 1983, the Army, faced with other acquisition priorities, relinquished their executive service status to the Navy [Ref.36]. A Joint Technology Assessment Group (JTAG) concluded that tiltrotor technology offered the best solution for a multi-service aircraft. The Bell-Boeing team submitted the only proposal in response to the Request For Proposal (RFP). As a result, a \$69 million Cost-Plus Incentive Fee (CPIF) contract was awarded to Bell-Boeing in April, 1983, based on their preliminary design of the JVMX aircraft. [Ref.36]

In 1984 the RFP for EMD was released and once again Bell-Boeing was the lone respondent. In January 1985, the JVMX was formally redesignated the V-22 Osprey (later, the MV-22 Osprey). Following the Milestone II DSARC review, EMD was approved in May 1986. Once again a contract was signed with Bell-Boeing. The contractors stood to share a greater percentage of the risk during this phase however, with the signing of a Fixed Price contract. [Ref.36]

From fiscal years 1986 through 1991, Congress appropriated approximately \$2.7 billion for the MV-22 program, the majority of which (\$2.2 billion) was for research, development, test, and evaluation (RDT&E). Despite opposition from the Secretary of Defense, Congressional support kept the program funded. [Ref.37] In 1988, Bell-Boeing completed the first MV-22 prototype, and begun the lengthy evaluation process. In March, 1989 the first successful flight was conducted. [Ref.36]

Shrinking Defense budgets once again brought the wrath of Defense Secretary Dick Cheney, who canceled the MV-22 program in April 1989. The Navy immediately responded with a reclama, and through intensive lobbying efforts, particularly by the Marine Corps, gathered enough backing for a congressional resolution that successfully reinstated the program later that same month. [Ref.37]

In April 1990 the first DOD flight evaluation was successfully completed. The first flight related setback occurred in June 1991, when test aircraft #5 crashed while conducting hover tests at Wilmington Delaware. The flight crew walked away unharmed.

As reported in the August 1991 edition of Rotor and Wing, the cause of the mishap was said to be due to the incorrect manufacturing of a flight control system component. [Ref.38:p.23-26] Perhaps a more accurate accounting of the cause was that it was due to "improper wiring of roll rate sensors in the primary flight control system that caused the pilot control inputs to get out of phase with the aircraft." [Ref.13:p.33]

There has also been speculation concerning the possibility of a compounding factor attributable to pilot error. This has been linked to the aircraft's fixed-wing power quadrant configuration, requiring somewhat opposite pilot control inputs from that normally associated with helicopter flight. [Ref.18] Regardless, the cause was not linked to tiltrotor unique technology, as reflected in the Rotor & Wing article's title; "Not A Killing Blow."

[Ref.38]

A fatal crash occurred just over a year later in July 1992. During arrival of aircraft #4 at Marine Corps Air Facility, Quantico Virginia, a fire broke out in one of the engine nacelles, causing the aircraft to plunge into the Potomac. Though nearly 780 flight hours had been amassed to that point, that crash which killed all occupants aboard, effectively brought the program to a halt [Ref.37].

Serious questions were again raised, at both OSD and in Congress, as to whether the MV-22 was "the" solution to the Marine Corps' operational requirement. Alternatives to the Osprey, such as conventional helicopters were suggested by OSD, and the topic of much of the Congressional debate. [Ref.37]

Many observers are under the perception that the post-mishap Congressional debate centered around technical issues, regarding whether or not the MV-22 was technically feasible to produce, and safe to operate. In reality, the discussions focused on funding. It was not a question as to whether or not the technical questions could be answered. Rather, it was whether or not the technical questions could be addressed within the schedule and financial constraints mandated by Secretary Cheney and Congress. [Ref.37] This is clearly evident in Congressional subcommittee dialogue between then Acting Secretary of the Navy, Sean O'Keefe, and Representative Les Aspin, former Chairman of the Procurement and Military Nuclear Systems Subcommittee:

The CHAIRMAN. It is the provisions then, in the appropriation bill that are 'engineeringly' unworkable, in particular, the 1996 date; is that what you are saying? Is that the part that is unworkable?

Mr. O'KEEFE. The project manager and the engineers involved in the program suggest that the combination of three different events in the statute is what is the show-stopper. The first is a requirement for a production representative aircraft which they determine to require on the order of about a 44 month production time frame. Second, there is a further requirement that it be tested by a certain date which cannot be accomplished in that window. The third feature is that \$790 million will not get you that program. [Ref.37:p.6]

In the simplest of terms, LtCol John Dillard, a military lecturer in the Acquisition curriculum at the Naval Post Graduate School, may have best described the environment in which Defense weapons systems are developed. Dillard stated unequivocally that "invention within a schedule is hard." [Ref.39]

Representative Beverly Byron of Maryland, may have captured the essence of what the Congressional activity was all about, when she emphasized that "the reason that we are looking at a helicopter option is the cost." [Ref.37:p.22] Once again the program eluded cancellation.

In January 1993 ground testing resumed. Flight testing followed that August. As of December 1995 MV-22 pre-production test aircraft had amassed over 1079 flight hours in 939 flights [Ref.40:p.4]. Approval to award Advanced Acquisition Contracts (AACs) for the first Low Rate Initial Production (LRIP) lot was granted on 7 February 1996. Along with it, came authorization for \$48 million in long-lead procurement. Production is anticipated to begin sometime in FY-97, with first deliveries going to the Marine Corps during FY-99. [Ref.36]

A discussion of the potential impact of MV-22 technologies and materials on CTR derivatives will discussed separately in Chapter V.

## **I. SUMMARY**

This chapter has recounted the history of tiltrotor research and development. The concept of vertical flight is as old as conventional flight. Defense sponsored tiltrotor research and development began in the early 1950s. Four prototype aircraft have been developed and flown, with varying degrees of success: the Transcendental Models 1-G and 2, the Bell XV-3, the Bell XV-15, and the Bell-Boeing MV-22 Osprey. Over the span of approximately 30 years and two generations of tiltrotor aircraft, the three historical barriers addressed in Chapter II were influenced by the following three contributions:

1. Government leadership and funding of tiltrotor research and development.
2. Proving the tiltrotor concept technically feasible.
3. Providing tiltrotor technology demonstration. [Refs.24 and 28]

These previous efforts however, have had little influence in addressing the barriers associated with lack of a supporting infrastructure and systems integration [Refs.2 and 20]. Though still an advanced concept, in that this technology has never been operationally fielded,

Tiltrotor technology is a mature technology unique to the United States. The V-22 production program is the logical development of these endeavors. [Ref.2:p.47]

Next, Chapter IV will present research pertaining specifically to initiatives involving the CTR. Potential CTR applications and their marketability will be explored and discussed. Next, previously conducted studies regarding the feasibility and viability of applications will be addressed. Finally, any barriers precluding CTR applications will be identified and discussed.



#### **IV. THE POTENTIAL MARKET FOR CIVIL TILTROTOR APPLICATIONS**

This chapter assesses the overall potential for commercial application of tiltrotor technology. Considerable market analysis in this area has previously been conducted.

To ultimately address whether CTR applications are dependent on MV-22 development, it is first necessary to examine the market for the CTR. In doing so, barriers that inhibit market introduction can be identified. The existence of these barriers, and the degree to which they can be satisfied or overcome, can provide the necessary link in establishing that dependence.

The chapter begins by providing a brief summary of various markets examined during a number of tiltrotor studies. Overall, according to the first of these studies completed in 1987, the tiltrotor is considered to possess "a large market potential." [Ref.41:p.2] However, the preponderance of the research will be confined to the "high density" or "short-haul" commercial passenger market. This will be done in order to provide focus, and more important, because this area is considered to possess the greatest potential for market penetration [Ref.41].

By way of introduction, the short-haul passenger market will be preceded by a discussion of the congestion problem our National Aviation System (NAS) is currently experiencing, and some of its root causes. Similar difficulties are being experienced in foreign markets.

Next, the sequence in which the tiltrotor concept came under consideration as a solution to the problem, will be reviewed. This will include a discussion of the expected method of employing the tiltrotor in the short-haul passenger environment. Experts testifying before Congress believe that employment of the tiltrotor in this fashion, holds revolutionary potential for solving the congestion problem [Ref.1].

Finally, four key tiltrotor studies will be identified and discussed. Each study addresses various aspects and considerations concerning the short-haul commercial passenger market. An overview of each study's findings and recommendations will be provided. The focus of this effort will be the identification and discussion of the barriers, risks, and issues highlighted in the four studies. It is considered vital that all these concerns be addressed and overcome to varying degrees, before implementation of a CTR system can be considered practical. [Refs.1, 13 and 41]

#### **A. POTENTIAL CIVIL AND COMMERCIAL APPLICATIONS**

The following section addresses the "most promising areas of potential commercial application." [Ref.41:p.8] The short-haul commercial passenger market, will be addressed separately. Other potential applications include, but are not limited to the areas identified in Figure 2.

User Groups:

- \* Corporate/Executive
- \* Commercial Operators
- \* Civil Government
- \* Offshore Oil
- \* Other

Vehicle Applications:

- \* High Density Passenger
- \* Cargo/Package Express
- \* Developing Region
- \* Resource Development
- \* Corporate/Executive
- \* Public Service

Figure 2. Potential Markets for CTR Applications. [Ref.41:p.8]

A brief discussion of some of the more prominent applications follows:

### **1. Corporate/Executive Travel**

Most Fortune 500 companies operate a number of aircraft for their top executives and leading customers. Many operate both helicopters and jets. Some have operations so extensive that they even have a separate vice president for air operations. Georgia Institute of Technology's Clifford McKeithan describes the current "typical" scenario of moving a company executive from company headquarters to a manufacturing plant in the conduct of required business:

A company helicopter picks him up at company headquarters and flies him to the regional airport. There he boards the company jet and flies a few hundred miles to an airport near the plant. Another helicopter takes him to the plant for his meeting. In this situation, which is quite common, the company uses three aircraft to accomplish the task.

With a corporate tiltrotor, a single crew and a single aircraft could transport the executive from headquarters to the plant. What speed advantage the jet possessed was lost, by the time required to fly by helicopter on both ends of the journey and to change modes. Tiltrotor aircraft could provide many of these companies the capability of improving the service and efficiency of their air operations. The tiltrotor offers corporate users speed, comfort, flexibility, and the ability to operate a single aircraft. [Ref.1:p.117]

## **2. Civil/Public Applications**

This umbrella category includes such areas as drug enforcement, Coast Guard, border patrol, police, fire, disaster relief, and medical transport. This is certain not to include all the possible missions and roles, but it reflects a large cross-section of those looked at in the initial study. The advantages of tiltrotor introduction into applications like those mentioned are considerable. [Ref.41]

Take drug enforcement as one example. As described by McKeithan,

A typical air mission consists of three phases: detection, surveillance and tracking, and interception and arrest. Generally, a long range, long endurance airplane such as a Falcon or a P-3 with radar is used for the detection phase. Once a suspected airborne smuggling operation is detected, a high speed turboprop or jet airplane is vectored by the radar aircraft to intercept and follow the smuggler. When the smuggler lands, trucks are often driven onto the runway to prevent the chase aircraft from landing. It is therefore necessary, as soon as a landing location(s) is postulated, to vector helicopters bearing DEA agents to the site to capture and arrest the smugglers and confiscate the illegal drugs. In this scenario, a minimum of three, and often more are used to complete the operation. The use of a tiltrotor aircraft for this mission has the obvious advantage of using a single aircraft for the entire three phases. The tiltrotor can mount the necessary radar for detection, it has the speed to intercept and follow most aircraft, and it can land without a runway to deliver the DEA agents. The tiltrotor can be a powerful tool in the fight against illegal drugs. [Ref.1:p.119]

### **3. Offshore Oil/ Resource Development**

McKeithan writes:

The off-shore oil industry has a unique problem. The workers on the oil rigs are paid premium wages from the time they board transportation to the rigs until they return to shore...The oil companies presently use helicopters for the task...At the further ranges, the helicopter becomes economically infeasible. Until now, no viable alternative existed. However, with twice the speed and twice the range of the helicopter, the tiltrotor can provide a reasonable means of transporting these workers, minimizing the amount of premium wages that must be paid for non-productive transport time. [Ref.1:p.118]

In regards to resource development, he adds:

Remote areas of the United States, such as Alaska, possess untold quantities of precious resources that cannot be developed or exploited due to a lack of a viable transportation system...In areas that need to be developed, the lower cost of construction of a vertiport over an airport, can easily offset the cost differential of acquiring and operating the [tiltrotor] aircraft. [Ref.1:p.118]

### **4. Cargo/Package Express**

Package express service continues to grow. However operations are beginning to experience difficulty in getting packages from the pickup point to departure airports because of the ground congestion. As described by Federal Express Managing Director John Finley, in this application the tiltrotor appears to provide its most value when operated in a city center to city center mode. [Ref.1:p.49]

## **B. THE PROBLEM WITH AIRPORT CONGESTION**

We know that the congestion and delay problems that we are now experiencing at our major airports will only get worse. It is estimated that the U.S. air passenger traffic will probably double within the next ten years. Yet, we are limited in our ability to meet this added growth in air

travel. We are limited by the air space that is available, by the ability to expand current airports, and by our ability to build new airports. [Ref.1:p.9]

[Congressman Pete Geren before House hearings on civil tiltrotor applications research.]

Congressman Geren's statement underscores the serious problems we are experiencing with the current and future capacity of our commercial transportation system.

### **1. Context of the Problem**

By the end of the century, total forecasted growth in enplanements in the United States is expected to exceed 74% [Ref.1:p.78]. By that same time, air travel in Western Europe is expected to come to "a near standstill". Similar trouble is anticipated in Japan. [Ref.1:p.78]

Right now, 21 primary airports each experience over 20,000 hours in annual delays, costing both airlines and the businesses effected by them, at least \$5 billion a year. By 1997 33 airports are expected to be effected to that same degree. [Ref.42:p.24] By the year 2000 that figure is expected to climb to 58 [Ref.41:p.28].

### **2. Principal Causes**

In general, this problem exists because as General Magnus points out, "although other advanced industrialized nations have good usage and capacity on their rail and bus systems, American demand has continued to decline for these modes while it increased for personal auto and commercial air travel". [Ref.43:p.1]

The major cause according to a 1991 study is that "many people are flying relatively short distances on relatively small aircraft" [Ref.44:p.2]. As Bell's Horner points out, "air travel is principally a short haul business" [Ref.1:p.89]. On average, according to McKeithan, 41% of all arrivals at the ten busiest U.S. airports originate from less than 300 miles away [Ref.1:p.111]. Figure 3 provides a breakout of those arrivals by city.

Percent of Arrivals from Cities less than 300 miles

<u>City</u>	<u>Percentage</u>
ATL	32
BOS	74
DEN	15
DFW	28
JFK	50
LAX	40
LGA	48
MIA	28
ORD	42
SFO	53

Figure 3. Short Range Arrivals at Ten Busiest U.S. Airports. [Ref.1:p.111]

In fact, 75% of all passenger flights are conducted within a 500 mile radius [Ref.1:p.90].

According to Port Authority's Muldoon, in the New York area, "commuter aircraft currently represent 19 percent of the total traffic, but accommodate only three percent of the passengers" [Ref.1:p.60]. In terms of just departures from the New York area airports, 44% are carrying only 18% of the total passengers, less than 300 miles [Ref.1:p.60]. A similar situation exists in Atlanta, where according to McKeithan, 44% of all arrivals and departures carry only 19% of the total passengers [Ref.1:p.104]. Combine all these factors and according to Horner, "a principal reason for congestion is that short haul and long haul aircraft use the same runway space" [Ref.1:p.90].

Add to the air congestion problem, the increased passenger flow to and from the airports along our cities' highways. As pointed out by the American Helicopter Society's Flater, "the roadways while they were ample for traffic, oh, 10 or 20 years ago, they now accommodate a volume which far exceeds their design capacity" [Ref.1:p.29].

### **C. THE SEARCH FOR A SOLUTION**

According to General Magnus, an increase in the capability of our National Aviation System to handle this escalating demand can be achieved in four ways:

1. Expansion of existing airports or construction of new facilities.
2. Enhancements in the Air traffic Control System (ATCS).
3. Use of larger conventional takeoff and landing (CTOL) aircraft.
4. Use of vertical takeoff and landing aircraft (VTOL) that can operate independent of conventional airport facilities. [Ref.43:p.1-2]

The first two options are generally considered the most difficult and expensive to achieve. As Congressman Geren explains: "expansion of our existing infrastructure is very expensive." [Ref.1:p.4] Even if funding were not the primary concern, Geren goes on to describe other key issues that: "because of the opposition of neighbors, because of the noise pollution, because of the growth in and around these airports--make it very difficult for them to expand." [Ref.1:p.4]

Larger CTOL aircraft are highly impractical for operations at the majority of secondary "feeder" and municipal airports. These facilities account for a large percentage of the route connections to and from the focal points of the congestion, but are often unable to accommodate a larger class aircraft. [Ref.13]

The use of V/STOL aircraft has generated the most attention. Flater believes employing such a concept "could increase the capacity of our existing airports by 30 percent or more without spending another dollar of our scarce revenues" [Ref.1:p.30]. McKeithan puts that estimate at about 23% [Ref.1:p.111].

Prior to 1973, a number of Government and industry studies explored the potential of various V/STOL concepts for use in relieving the congestion, and improving the regional transportation system. However, as a result of the fuel crisis, the Government's push for fuel efficiency, and the inefficiencies of most V/STOL designs, the conduct of these studies was drastically curtailed. [Ref.41:p.9]

Though V/STOL configurations using other than rotors or propellers have been studied, for a number of reasons, they have generally been dismissed as impractical for commercial purposes. [Ref.25:p.122-124]

One significant reason discussed in Chapter III, was that working against the potential benefits of most configurations "are the increased fuel requirements of low speed and hovering flight" [Ref.22:p.7]. Another disqualifier in the commercial environment may be that:

The tremendously hot exhaust also pose several problems with takeoff and landing. A minor one was the possibility of damage to the landing surface. [Ref.25:p.123]

This notion is supported by the restrictive requirements under which the AV-8 Harrier must operate. Other problems with commercial application of these configurations include gust sensitivity, and handling qualities. [Ref.27:p.9-3 and 9-4]

In 1983, an FAA-sponsored program determined that the conventional helicopter was an unsatisfactory choice for satisfying this requirement. The study's findings indicated that this was due to "a lack of capacity, high operational costs, and high noise levels." [Ref.42] But there's more obvious reasons why the helicopter is ill-suited in this role. Hellman maintains that the helicopter is really only practical for what is often termed "ultra-short haul." [Ref.25:p.73] This primarily involves operations from city-center to local airports and back. "Ten or twenty miles being the average." [Ref.25:p.73] This is also supported by McKeithan who explained that "the limited speed and range of the

helicopter has limited its potential for city-center to city-center transportation."

[Ref.1:p.112]

#### **D. THE TILTROTOR AS A SOLUTION**

Beginning in 1976, two X-15s were built as tiltrotor technology demonstrators. This fuel efficient design (by V/STOL standards) improved on previous developmental efforts begun in the 1950s by the Transcendental and XV-3 prototypes. The XV-15 began performing its intended role in 1981. Development of the MV-22 was also initiated that year. [Refs.24 and 36]

Coincidence or not, over the past 15 years, users of commercial and civil aircraft have begun to realize the tiltrotor's vast potential. Not only for application in short-haul commercial passenger service, but in a myriad of other markets as well [Refs.1, 41, 43 and 44].

Approximately ten years ago, a series of new studies began. Though similar in purpose, these new efforts have focused exclusively on tiltrotor technology to satisfy short-haul commercial requirements, as opposed to the entire spectrum of V/STOL configurations. [Refs.41 and 44]

Commercial use of the tiltrotor is still an advanced aviation concept, in that, there has never been a variant, military or commercial, in operational service. The technology itself however, is considered proven and mature based on over 40 years of Defense research and development. [Refs.2, 24, 28, 29, 31 and 37]

## **E. TILTROTOR EMPLOYMENT IN THE SHORT-HAUL PASSENGER MARKET**

Several experts put the end result of these short-haul related congestion problems in terms that the traveling passenger can relate to. Hellman reveals that studies conducted over 25 years ago by the Port of New York Authority were already showing the effects of the problem. These studies showed that "travelers using short-haul jetliners average only 76 mph on a city-center to city-center trip between New York and Washington--and only 66 mph between Chicago and Detroit" [Ref.25:p.70-71]

McKeithan provides a more recent New York scenario:

From downtown Manhattan, the traveler can expect to spend approximately 35 - 50 dollars and 45 minutes for a cab ride to LaGuardia airport. Since most of the business travel from our major cities is of lengths of less than 300 miles, the traveler spends more time in ground transit than in the air. [Ref.1:p.112]

The tiltrotor is envisioned to be most advantageous in the range from 50 to 300-500 miles [Refs.25, 41 and 44]. This happens to be the range within which, the current short-haul carriers, shown to be the root cause of the congestion problem, also operate. [Refs. 1, 41, 43 and 44] Short-haul service can sub-divided into three different types of services or travel:

1. Vertiport-to-Vertiport
2. Feeder
3. Transfer [Refs.13 and 44]]

Vertiport-to-vertiport service involves origin to destination service between two metropolitan areas. Feeder service involves travel between vertiports and secondary airports outside metropolitan areas. Transfer service involves connecting either vertiport or feeder airport travelers with long distance service. [Refs.13 and 44]

The helicopter is still seen as viable when used locally for feeder and transfer service. The tiltrotor can certainly fill these requirements as well. However, the tiltrotor's real solution lies in its ability to eliminate the use of airports all together, or in intra-city vertiport-to-vertiport service. As explained by General Magnus, these aircraft "using a network of small facilities (vertiports), may prove attractive and profitable by replacing existing CTOL aircraft on short-haul routes... in heavily trafficked corridors, opening up the time slots presently required by these short-haul CTOL aircraft for additional capacity for long-haul CTOL aircraft." [Ref.43:p.2] As described by Hellman, "their (the tiltrotor) greatest promise lies in their ability to bring the airport to where the people are, rather than vice versa." [Ref.25:p.74]

Figure 4 depicts the comparative total times for different combinations of transportation modes, required to transport a traveler from city-center to city-center, a distance of 200 miles. The tiltrotor by comparison, is both more efficient and effective in accomplishing this task. [Refs.1, 25, 41, 43 and 44]

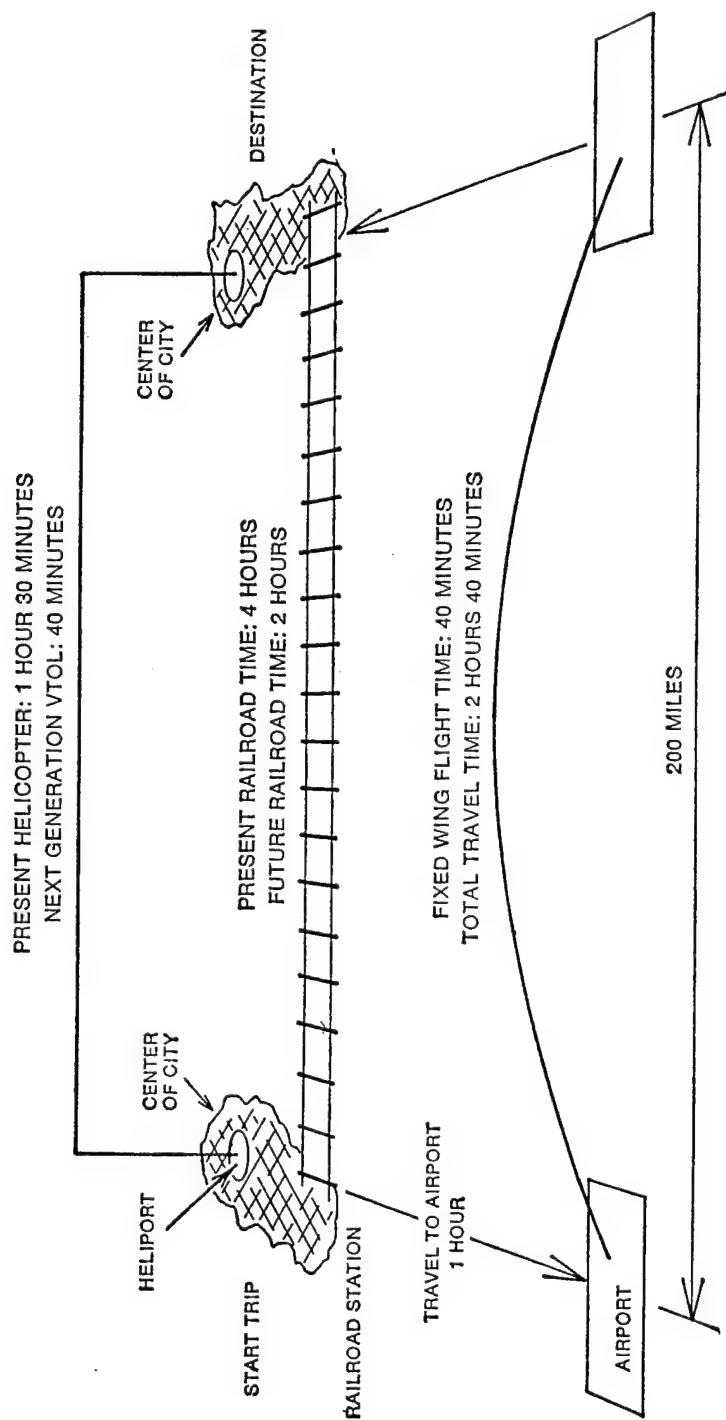


Figure 4. Comparative Times for Railroad, Fixed Wing and VTOL for a 200-Mile City-Center-to-City-Center Trip. [Ref.25 :p.75]

## **F. MARKET STUDIES OF CIVIL TILTROTOR POTENTIAL**

Numerous studies on the potential of V/STOL technology to alleviate the airport congestion problem have been conducted over the years. A review of four of the market studies completed since 1987, specifically addressing the tiltrotor in this role will be reviewed. A summary of the most significant findings, barriers or issues, and recommendations contained in those reports follows. More detailed information in regards to each study is provided in Appendix B.

### **1. Civil Tiltrotor Missions and Applications - Phase I**

In 1985, the FAA Administrator proposed a joint civil tiltrotor study with NASA and DOD. The study was contracted out and completed by Boeing, Bell Textron, and Boeing Vertol in July of 1987. The study examined the potential for employment of tiltrotor technology across a wide range of applications. Those applications were discussed earlier in this chapter.

The major finding reached in the study was that, overall, the civil tiltrotor has large market potential, particularly in the short-haul passenger market [Ref.41]. Concerning this specific market, as opposed to other modes of air transportation, tiltrotors offered better potential to improve interurban air transport service [Ref.41].

The study also identified potential barriers to implementation, and risk areas that required attention. They included gaining public acceptance, technical validation, and ensuring economic competitiveness. The most significant issue concerned the need to develop a supporting infrastructure. [Ref.41]

As a result of the Phase I study's findings, the primary recommendation was the development of a National Plan for a tiltrotor transportation system. It called for a joint effort between the FAA, NASA, DOD, and Industry. [Ref.41] Other specific recommendations included development of a tiltrotor technology demonstration program, and that CTR development be keyed off of the MV-22 program [Ref.41].

## **2. Civil Tiltrotor Missions and Applications Phase II**

Completed in February 1991, the Phase II study expounded on the research conducted in the initial Phase I study. However, its focus was limited exclusively to the "high density," short-haul market identified previously as having the greatest market potential [Ref.41].

The overall finding was that in the short-haul market "a commercial tiltrotor is both technically feasible and economically competitive" [Ref.44:p.i]. Additionally, commercial tiltrotors could ease congestion and extend the useful life of existing airports. [Ref.44]

Major barriers and issues effecting successful CTR introduction included the difficulty of validating the technology for commercial applications, and that both operators and travelers will demand the technology be proven. Once again, the most important revelation was that development of a CTR was not sufficient. The need for a supporting air/ground infrastructure was deemed critical. [Ref.44]

The study's findings, and the barriers and issues identified, led to agency specific, recommended responsibilities. The most significant were:

General

- \* Formation of public-private partnership to pursue national tiltrotor plan.
- \* Department of Transportation to lead.
- \* Continue NASA/FAA/Industry cooperation.

NASA

- \* Sponsor technology demonstration program using:
  1. MV-22s.
  2. Upgraded XV-15.
  3. Simulators.
- \* Expedite acquisition of MV-22 engineering test data. [Ref.44]

**3. "Eurostudy"; A European Regional Transportation Study**

A third major study was the Eurostudy which was a detailed examination of the potential for a regional European tiltrotor transportation system conducted in 1992. Those conducting the research included Bell Textron, Boeing Helicopters and Boeing Commercial Airplane Group, Alenia, British Aerospace, and Dornier.

The major finding reached in the study was that potentially, there was substantial demand for a European tiltrotor, but that demand was highly sensitive to fare levels.

[Ref.45:p.4] The study also pointed out that the military MV-22 provides the necessary technology base [Ref.45].

The most significant barrier to successful introduction of a European CTR is the heavy reliance on rail transportation. This will require a major paradigm shift in European thinking. [Ref.45] Other significant barriers include:

- \* Infrastructure components need to precede or accompany CTR development.
- \* Civil acceptance awaits military MV-22 operational experience. [Ref.45]

The study posed only two recommendations for the require "next steps"; one general and one specific:

- \* Industry and European Government cooperation.
- \* A demonstration program may be needed. [Ref.45]

#### **4. Civil Tiltrotor Development Advisory Committee (CTRDAC) Report to Congress**

Under Section 135 of the Airport and Airway Safety, Capacity, Noise Improvement, and Intermodal Transportation Act of 1992 (PL102-5810), the U.S. Congress directed the Secretary of Transportation to establish a Civil Tiltrotor Development Advisory Committee (CTRDAC). [Ref.13] In October of 1992 a Congressional mandate required the committee to examine the costs, technical feasibility, and economic viability of integrating CTR aircraft into our national transportation system.

This committee, comprised of representatives from public, private, and industry concerns, held their first meeting on 20 May 1994. The committee's mandate was based on the following realities:

- \* National airspace congestion problem.
- \* Previously conducted tiltrotor market studies.
- \* Commercial interest in the tiltrotor concept as a result of V-22 development, and on-going NASA research.
- \* U.S. preeminence in tiltrotor research and development. [Ref.13]

A key goal of the committee was to assess how aircraft and infrastructure development costs should be allocated between Government and industry. The report to Congress was completed in December 1995. [Ref.13]

The major finding reached by the CTRDAC was that the CTR system's success is contingent upon overcoming significant risks and uncertainties [Ref.13]. The majority of the risks and uncertainties are associated with the fact that:

- \* No one agency controls the resources necessary for CTR system development.
- \* Decisions to manufacture CTRs, develop air/ground infrastructure, and operate services are interdependent. [Ref.13]

A significant number of barriers, risks, and issues were addressed in the report. They can best be summarized and categorized under the five historic barriers presented in Chapter II:

- \* Public/User acceptance regarding CTR safety and aircraft noise levels.
- \* Technical Risks associated with civil technology validation and FAA aircraft certification.
- \* Financial Risks involving high capital costs, and expenditures required to meet certification requirements.
- \* Infrastructure delays effect potential investment.
- \* Systems integration problem associated with resource control and decision authority. [Ref.13]

In regards to the committee's recommendations, two stand out as being most significant. They are:

- \* Creation of public/private partnership to coordinate all issues pertaining to a CTR transportation system, particularly infrastructure development.
- \* Initiation of a tiltrotor aircraft/system demonstration program to:
  1. Assess community/operator acceptance.
  2. Evaluate environmental impact.
  3. Gain operational experience.
- \* Proceed with an integrated, 10 year, CTR aircraft and infrastructure program (research, development, test, and demonstration). [Ref.13]

## **5. Synopsis, Interpretation, and Expansion of Market Studies**

The NASA/FAA sponsored Phase I study identified several market segments, the largest of which was for a 36-45 passenger tiltrotor in the "high density" or short-haul commercial passenger market. [Ref.41] The Phase II effort focused on the economic performance and potential world wide market demand for a 40 passenger vehicle, exclusively in the previously identified short-haul market. [Ref.44]

Additionally, in the second study, market demand was examined in four U.S. corridors, the Northeast showing the strongest potential. This included vertiport-to-vertiport, feeder, and transfer requirements. A "lower bound" forecast for the number of aircraft required to support the market potential was constructed. This lower bound consisted of vertiport-to-vertiport and feeder requirements for the four corridors. Transfer requirements were added to obtain an "upper bound." [Ref.44] The number of aircraft produced to support U.S. demand based on this criteria, along with worldwide demand in the year 2010, is presented later.

The "Eurostudy" evaluated a 40 seat tiltrotor against the competition from the emerging high-speed rail system. Dependent on fare levels, an estimated 130 to 1200 CTRs could be called for by 2010. [Ref.45]

A Japanese market study, now underway, is due out later this year. Hence, it was not summarized here. Preliminary feedback indicates a Japanese market for approximately 300 to 400 aircraft [Ref.13].

CTRDAC world market projections, for the year 2010, factor in those aircraft required to support other potential applications identified in the Phase I study. Again using a lower and upper bound, this latest research on worldwide demand for a 40 seat tiltrotor is contained in Figure 5. [Ref.13]

<u>Market Region</u>	<u>CTR Forecast Range</u>
Four major U.S. Corridors	235 - 325
Other North American Corridors	150 - 200
Europe	300 - 400
Japan	300 - 400
Oceania	100 - 125
Total Short Haul	1085 - 1450
Other applications	75 - 150
Total	1160 - 1600

Figure 5. Worldwide Demand Forecast for 40 Seat CTR in 2010. [Ref.13:p.64]

There are numerous barriers, risks, and unresolved issues highlighted in each of the studies. To varying degrees, all must be addressed in order to successfully field CTRs in profitable quantities for both manufacturers and operators. These barriers must also be

addressed in order for the CTR to have a favorable impact on the short-haul passenger market. Four major barriers were highlighted in the tiltrotor market studies. They are:

- \* Public acceptance
- \* Technical Risks
- \* Financial Risks
- \* Lack of a supporting infrastructure [Refs.13, 41, 44 and 45]

Though eluded to, but not specifically mentioned in the other studies, the CTRDAC adds systems integration as a fifth [Ref.13]. Dr. Robert Rosen of NASA also spoke of a CTR systems barrier. During Congressional testimony on CTR applications Rosen maintained that the major barrier to introduction of the CTR is "difficulty with the development of the overall system." [Ref.1:p.135]

In addition to their applicability to the CTR, the reader may recall that these five barriers are historic in nature, and were discussed in detail in Chapter II. The reader may also recall that the last two barriers were associated with the attempted introduction of the helicopter into the short-haul commercial passenger market. These two barriers were seen as the primary reasons for the helicopter's limited success [Ref.2 and 20].

To realize the full potential of the CTR, the required infrastructure must accompany the aircraft's introduction. There are numerous considerations that must be addressed in providing for that full potential. For example, a CTR system can only operate profitably when supported by a network of vertiports designed to handle commuter

service in large quantities. In 1990, Boeing's Renouard estimated each vertiport would require a four to five acre area in order to accommodate the anticipated volume of CTR traffic. [Ref.1]. In 1995, the CTRDAC put that estimate at 20 to 30 acres [Ref.13]. The use of existing, significantly smaller heliports in and around our cities, would not suffice.

Terminal area instrument approach capabilities must also be considered, particularly during inclement weather. Carriers cannot profit if they cease operations due to Instrument Meteorological Conditions (IMC).

The real issue in regards to the systems integration problem, is one of commitment. The CTRDAC begins to shed light on this. It writes:

A manufacturer will only launch a CTR program when it believes it can sell enough units over a short enough period of time at a price sufficient to cover investment and manufacturing costs while earning a return on the capital employed. [Ref.13:p.62]

However, as the CTRDAC goes on to explain:

A CTR launch decision is not purely technical or economic. Actions (or non-actions) by potential operators and the Government will be principal considerations as a manufacturer decides when and if a launch decision is made for a CTR program. [Ref.13:p.63]

As far back as 1990, Norman Augustine, Chairman of the Tiltrotor Technology Subcommittee of the FAA Research, Engineering, & Development Advisory Committee, also believed the systems integration barrier was primarily associated with the need for commitment. In testimony before Congress, Augustine described the problem in a rather

Catch 22 fashion. He maintained that manufacturers were unlikely to commit to production:

Without first having order commitments from aircraft operators. Aircraft operators in turn, are unwilling to commit to the purchase of a fairly revolutionary new aircraft without greater understanding of their operational economics and reliability, along with assurance that needed vertiport facilities will be available. Operators of facilities in turn, are unwilling to commit to reasonably costly new capabilities until it is clear that there are aircraft, and passengers who are prepared to use them. [Ref.1:p.166]

It was for these very reasons that the two primary recommendations were made.

First, in regards to the need for a partnership, a CTR system requires a coordinated, substantive, long-term commitment from numerous independent interests [Ref.13:p.88]. These independent interests, such as commercial carriers or vertiport operators, control varied degrees of the required resources and decision-making capability associated with the entire CTR system.

Concerning the need for a demonstration program, Augustine argues that "first and foremost, potential future buyers and operators of civil tiltrotors seek to be convinced that the technology and economics are viable before they will commit funds and place orders for aircraft representing such a departure from conventional practice." [Ref.1:p.166]

## **G. THE POTENTIAL COMPETITORS**

Success in exploiting the world-wide market for CTR applications is critically dependent on the ability of manufacturers to make their product available before their

competitors. There are very few companies with the capability to compete in this race to production.

### **1. The Americans**

Bell Helicopter Textron and Boeing Helicopters Division are currently the only companies with extensive, previous experience in the tiltrotor arena. To date, they have invested over \$600 million in tiltrotor programs. Additionally, they have stated their intent to work together on any size CTR project. Strictly from a technical and manufacturing standpoint, they will be prepared to produce a 40 passenger CTR by the year 2007.

[Ref.13:p.71]

### **2. The Europeans**

In 1987, a joint European effort was launched by five countries to compete in the development of a tiltrotor aircraft. This multi-national endeavor, designated the European Future Advanced Rotorcraft (EUROFAR), resulted in a \$225 million plan to develop a prototype by 1997. Though this original plan was not approved, a Phase II EUROFAR team comprised of France, Germany, and the United Kingdom, has been underway since 1993. This team is believed to possess the requisite technical expertise. To be competitive, it is believed that the addition of government subsidies will be necessary.

[Ref.13:p.71-72]

### **3. The Japanese**

The Japanese are very interested in the tiltrotor, and at one point contracted with Ishida, a Texas based firm, to develop the TW-68, a "tiltwing" aircraft [Ref.1:p.158]. According to Congressman Weldon however, "Ishida folded up a few years ago." [Ref.3]

### **4. The Russians**

The Russians have admitted an interest in tiltrotor technology and have conducted some development work. Beyond that, they have offered very little specifics. [Ref.1:p.158] It is believed that this has included "predesign work and wind tunnel testing." [Ref.13:p.72] But due to financial constraints, their aerospace industry is undergoing significant restructuring. "A Russian tiltrotor would not be expected to appear until well into the next century, and then perhaps as a joint development." [Ref.13:p.72]

### **5. Other Arrangements**

Though this is not currently the case with the tiltrotor, there has been a recent trend toward U.S. aerospace companies establishing relationships with non-U.S. companies. Due to large investments in time and the early negative cash flows, this type arrangement has been exploited in order to develop and build new generation commercial aircraft. [Ref.13:p.72-73]

A number of competitive scenarios are possible, however it is safe to assume that the size of the tiltrotor market will limit the number of companies that elect to get involved. Furthermore, only major companies will launch CTR programs. [Ref.13:p.72]

## **H. SUMMARY**

This chapter has identified the various applications in which the tiltrotor concept is believed to hold potential. Studies indicate the short-haul market appears to hold the greatest promise [Refs.13, 41 and 44]. The congestion and over-capacity problem within our national aviation system, and its relationship to short-haul transportation requirements was described. Additionally, how employment of the tiltrotor concept in the short-haul passenger market is believed to be the solution to this national problem, was explained. [Refs.13, 41, 43 and 44] Furthermore, a summary of four key tiltrotor market studies was summarized. Finally, the potential tiltrotor market competitors were identified and discussed.

Successful introduction of the tiltrotor in the short-haul market has implications far beyond simple financial rewards for aircraft manufactures and operators. Employment of the tiltrotor concept as part of a new and innovative national transportation system has revolutionary implications. It infers significant societal benefits for the individual traveler, and the national as a whole. [Refs.1, 13, 41 and 44]. However, as presented here, significant risk and uncertainty remains [Ref.13].

Next, Chapter V will identify, analyze, and discuss any evidence of a dependence between Defense development of the MV-22, and potential future innovation of the CTR. Learning experience derived through MV-22 development, enabling technologies, as well as other benefits will also be addressed.

## **V. THE CIVIL TILTROTOR'S DEPENDENCE ON THE MV-22 OSPREY**

The tiltrotor "concept" has been proven technically feasible through well over 40 years of Defense development, and three generations of tiltrotor aircraft. The CTR has not. However, with each successive generation, the experience gained and lessons learned from previous undertakings becomes the technology base upon which each new tiltrotor aircraft is developed. [Ref.28]

This trend will likely continue with development of the CTR, both in terms of Government support, and its dependence on previous tiltrotor aircraft. As explained in the Phase I market study: "all designs make use of V-22 military technology." [Ref.41:p.22]

This chapter will examine the extent to which the CTR is dependent on Defense development, procurement, and operational employment of the MV-22 Osprey. First, the role of the U.S. Government in past, present, and future tiltrotor initiatives will be discussed. Next, the MV-22 contributions made through operational experience and technology demonstration will be explored. This will be followed by an examination of the various CTR configurations designed and envisioned for commercial use. Finally, various CTR enabling technologies, technology transfers, and other benefits derived from development of the MV-22 will be identified and discussed.

## **A. THE U.S. GOVERNMENT**

Government development of the tiltrotor, dating back to the early 1950s, was intended primarily to benefit the Defense Department [Refs.13 and 27]. However, Government involvement in the CTR is not new.

### **1. Providing the Leadership**

According to Georgia Tech's McKeithan, NASA has always had a standing offer "to help any U.S. manufacturer come up to speed on tiltrotor technology." [Ref.1:p.109]

Furthermore, according to McKeithan, those involved in the XV-15 project as far back as the late 1970s considered tiltrotor technology to hold more promise in the civil sector than in the Defense Department [Ref.1:p.109].

As the original JMVX program was launched and Government studies came to a close, resources were shifted toward the exploration of civil applications of tiltrotor technology. A majority of these efforts were led by Dr. John Zuk, the Chief of the Civil Technology Office at NASA Ames Research Center [Ref.1:p.109]. Dr. Zuk later became the Study Director for that first, NASA sponsored, Phase I tiltrotor study [Ref.41]. As a side note, Dr. Zuk was a major supporter of this thesis study, and now works out of NASA Ames' Tiltrotor Project Office.

During the 1980s the FAA also studied the potential for civil application of the tiltrotor. Their focus was in exploring its potential for relieving the airport congestion problem, discussed in Chapter IV [Ref.1:p.109]. Later, the FAA opened a Civil Tiltrotor Special Projects Office. The title was ultimately changed to the Vertical Flight Programs

Office, to consider issues involving other VTOL concepts, such as the helicopter.

[Ref.1:p.146]

Finally, in 1992 Congress passed the Airport and Airway Safety, Capacity, Noise Improvement, and Intermodal Transportation Act of 1992. Section 135 of the act directed the Secretary of Transportation to establish a Civil Tiltrotor Development Advisory Committee, to study the potential use of the tiltrotor as part of a national transportation system. Its results were summarized in Chapter IV. [Ref.13]

## **2. Sharing the Financial Burden**

In the past, the Defense Department, with NASA support, has funded the majority of tiltrotor research. [Refs.1:p.109 and 13:p.17] For aircraft manufacturers to launch a CTR production program to support the national transportation system, they will be required to invest over a \$1 billion. However, they will not do so until the technical and market risks are considered manageable. Risk reduction will require Government cooperation, leadership, and financial relief. Without the "partnership" discussed in Chapter IV, manufacturers would be unwilling to manufacture CTRs, with no guarantees that the rest of the CTR "system" will materialize. It would be unlikely, no matter how promising the market, that the CTR would happen "in the near future." [Ref.13:p.93]

However, Bell's Horner suggests another option for securing CTR cost-sharing. In Congressional testimony Horner suggested that Bell-Boeing might consider "the possibility of going into the international market and look for a source of funding." [Ref.1:p.127] This action might overcome a major obstacle for the manufacturers,

however it would do little in forming the coalition that is considered essential in solving the nation's short-haul transportation problem. [Refs.13, 41 and 44]

Such action does not guarantee carrier orders, nor answer questions regarding infrastructure. Prospective CTR carriers would still require that questions concerning infrastructure be answered before they commit to buys. Additionally, operators would still be concerned with public acceptance, reliability, and operating costs. [Ref.13:p.94] Local authorities, including potential vertiport operators, would still need to see that adverse environmental issues (external noise in particular) can be mitigated through development. [Ref.13:p.94] As described in Chapter IV, this situation creates an uncertain, high risk, Catch 22 scenario.

All entities involved in the national partnership stand to benefit from its future prospects. However, this "systems problem" involves too many technical and financial risks. No single entity can shoulder their individual financial responsibilities in isolation. [Ref.13:p.93] Leadership and financial resources therefore, are two of the key ingredients considered necessary in breaking the Catch 22 cycle. As a result, with the exception of the Eurostudy, a key recommendation of the previous research was for a Government led, cost-sharing partnership [Refs.13, 41 and 44].

## **B. CTR DEPENDENCE ON MV-22 OPERATIONS**

If the tiltrotor follows the classic route, the civil tiltrotor application will wait until the military version has been proven. Therefore, in order for the United States to maintain the lead in tiltrotor technology, the Department of Defense must continue development of the military V-22. [Ref.1:p.26]

This statement was made by Florida Representative Tom Lewis during 1990 Congressional hearings on Civil Tiltrotor Applications Research. It is not unreasonable to assume that Congressman Lewis' testimony was, in reality, out of concern for the future of the MV-22, as opposed to the CTR. That assumption would be valid, based on the military program's unstable history throughout the late 1980s, and the coalition that was built during that period to keep it alive. Numerous stakeholders provided Congressional testimonial pressing for continuance of the MV-22 program [Refs.1 and 37]. As a result, much of the validity concerning the need for the MV-22 to serve as a CTR prerequisite may have been negated.

### **1. Military Operational Experience**

Still, as discussed in Chapter II, the belief that the military must serve as the proving grounds for new aviation concepts is not new, and is a view held by many. [Refs.1, 2, 5, 12, 13, 19, 44 and 45] For example, the Phase II study states that "military production aircraft may contribute to proving the tiltrotor concept by demonstrated success." [Ref.44:p.4] Likewise, the Eurostudy advises that "civil acceptance awaits operational experience from military tiltrotor aircraft; i.e., safety, reliability, and environmental suitability." [Ref.45:p.5] Other sources provide more tangible justification for the reasons why military experience is needed. The CTRDAC in its Report to Congress states that:

As the military gains experience flying the V-22 over thousands of hours, this will add to the general knowledge of tiltrotors and will be helpful to designers of the CTR...there would be enough similarities in certain critical

components that extensive V-22 operational experience would provide some helpful information to civil designers in terms of failure modes. While the V-22 and the CTR would be used for different missions, the basic aeromechanics and flight characteristics are common and would benefit CTR design activity. [Ref.13:p.20]

Morris Flater, former President of Hubexpress Airlines, and current President of the American Helicopter Society and CTRDAC member, was even more specific. In testimony before Congress, Flater, then speaking from the perspective of an operator, explained why he thought the potential experience gained through flying the MV-22 was necessary. He explained that [he]:

Would like to see the V-22 Osprey adopted as a military program, so that when it becomes available commercially, the engines, rotors, transmissions, and major components will have the 6,000 hours TBOs (time between overhauls) we need in commercial aviation to make the aircraft cost effective. Only with extensive military experience will the FAA extend component overhaul and maintenance intervals into ranges we require. [Ref.1:p.42]

The CTRDAC supports this idea as well. It states that:

By flying these relatively large tiltrotor transports for some years, the military will provide the necessary experience to judge whether an aircraft such as the V-22 tiltrotor has the potential for profitable applications in the civilian sector. [Ref.13:p.A-3]

NASA's Rosen may have addressed the need for operational experience better than anyone. In a prepared statement presented to Congress, Rosen clarified the critical difference between what is gained from an operational aircraft, as opposed to strictly a technology demonstration aircraft. He wrote:

Successful experimental aircraft programs, such as the XV-15, can provide validation of new vehicle concepts, but a great deal of risk remains for

product development. There is very little operational or manufacturing experience in an "X" aircraft on which to base an economic decision for a commercial aircraft...The first-generation vehicle is often a military vehicle. That military vehicle provides a data base of operational experience that helps reduce the uncertainties for potential civil users and regulators... A basis for civil certification is provided. Civil tiltrotors may fall into this category and could be accelerated by successful development and operation of a military aircraft. [Ref.1:p.140]

The operational experience that the CTR would gain from Defense procurement and fielding of the Osprey is substantial. According to The CTRDAC, the MV-22 fleet will have accumulated approximately 60,000 flight hours by 2005, still two years prior to anticipated CTR production Ref.13:pps.20 and 71].

## **2. Technology Demonstration**

As of yet, no representative CTR prototype exists. Still, the four CTR market studies, agency representatives, and individual experts, all recommend that the CTR be presented to stakeholders through a technology demonstration program. Until a CTR demonstrator is in fact prototyped, the studies suggest an interim solution. [Refs.1, 13, 41, 44 and 45]

The Phase II study recommends that NASA sponsor the interim program "using V-22, upgraded XV-15, and flight simulator assets." [Ref.44:p.vi] It further suggests using two MV-22s for a "30-day North American demonstration tour," package express trial, and both enroute and terminal ATC operations. [Ref.44]

The CTRDAC discussed the merits of using the XV-15 as opposed to the MV-22, but rejected that idea because "the V-22 is very close in size to a 40 passenger CTR," and

"believed that local communities would rather see a vehicle the same size and weight as a potential CTR." [Ref.13:p.90] Furthermore, the CTRDAC believed that V-22 demonstration "would be absolutely essential to gain knowledge related to community acceptance, particularly in the areas of noise and safety." [Ref.13:p.91-92]

As opposed to a "straight V-22," the CTRDAC recommended a two-phase approach using a modified Osprey. "Phase A" would primarily consist of ground and wind tunnel testing, and limited flight testing to evaluate both necessary and desired, commercially unique features. [Ref.13:p.89-90] These commercial advances will be discussed later, at length.

Phase B would involve actual demonstration of a modified MV-22 equipped with these integrated civil features. Development and assembly would occur from 1998 through 2001, while the actual demonstration would be conducted between 2001 and 2003. [Ref.13:p.90]

The CTRDAC maintains that the required commercial advances eluded to cannot be addressed through MV-22 operations. [Ref.13:p.A-5] To some extent, the researcher agrees. However, some advances are being mitigated to varying degrees; not through operations, but through development of the MV-22. Additionally, there are others. Those that are relevant will be addressed in further detail.

One might ask: What if the military MV-22 program were canceled prior to a production decision? What tiltrotor would then be used to fill the interim demonstrator requirement? In Congressional testimony Bell's Horner explained that the original plan

involved working with DOD, and actually pulling two production MV-22s off the production line. He went on to explain that if the program were killed prior to reaching a production decision, that they (Bell-Boeing) would still use the pre-production MV-22 prototypes [Ref.1:p.129-130].

In regards to a demonstration program's effect on the lack of supporting infrastructure, the CTRDAC acknowledges that "a full network of large, sophisticated vertiports will not spring into existence all at once." [Ref.13:p.49] However, it is expected that a CTR demonstration program will aid infrastructure development, by enabling the establishment of a "start-up network" of vertiports. This will minimize initial vertiport investment, while demonstrating how such a CTR system can successfully function. [Ref.13:p.49]

Both the Phase II study and the CTRDAC recommended that following the interim MV-22 solution, that the demonstration program should continue with "Phase C," and the use of a CTR2000 prototype. This phase would span the years 2003 to 2008 [Ref.13 and 44].

### **C. THE CIVIL TILTROTOR (CTR)**

One could suggest: Why not just use a slightly modified MV-22, or a "stretched V-22" for commercial passenger service? To a very limited extent, excluding some commercial certification considerations, this is not totally impossible. It is more a question of what is marketable and economically practical.

## 1. The MV-22; Built to Military Specifications

As pointed out by General Magnus, "the V-22 was built to military specifications."

[Ref.12] These specifications emphasize "improved performance and combat survivability." [Ref.41:p.15] As a result, in meeting these specifications, the design "appreciably increases fuel burn, adds structural weight, and adds complexity."

[Ref.44::p.18]

The MV-22 was designed to meet the mission requirements of the Services. Requirements for damage tolerance features, infrared suppression, rear loading capability, folding rotor systems, and other "mission equipment," add substantially to manufacturing costs. [Ref.44:p.18]

The type materials and manufacturing methods take into account the rigors of aggressive flight regimes, and harsh operating environments. The consideration given to the corrosive shipboard environment during the design and manufacturing of durable, corrosive-resistant composite materials, is an example. [Ref.44:p.18] Ballistic tolerant fuel cells are another.

Defense contracts require manufacturers to comply with the constraints imposed in meeting "milspecs." These contracts and the Government acquisition process require lengthy, complicated, and costly processes to handle paperwork, accounting, inspections, and documentation. [Ref.44:p.18]

CTR technology is not at the point where an economically viable, 40 passenger, commercial derivative can be built. In testimony before Congress, Boeing's Renouard explained that:

Although the V-22 is a key step on the road to widespread use of civil tiltrotors...it is not possible to merely repaint or tweak the military version in order to produce a commercially viable tiltrotor alternative. [Ref.1:p.70]

In order to reduce both the technical and financial risks, and for commercial certification of a CTR to take place, there must be further commercial advances in, among other things:

- \* Composites.
- \* Manufacturing processes.
- \* Flight controls.
- \* External noise reduction.
- \* Internal noise reduction/Vibration.
- \* Contingency power.

[Refs.13, 41 and 44]

## **2. Initial CTR Designs**

One of the priorities of the Phase I CTR study was to identify practical CTR configurations which could best support the particular markets under assessment. "A V-22-based commercial tiltrotor can realize significant savings in weight and cost by eliminating military mission and survivability features." [Ref.44:p.27]

Changes for commercial operation can be divided into two categories. The first are those changes that are absolutely essential in order to gain FAA certification. The second category include changes that are considered desirable from a cost savings perspective, or one that adds passenger comfort or accommodations. [Ref.44:P:27]

Increased power output to accommodate one engine inoperative (OEI) requirements, is an example of changes necessary for certification. Redesign of the fuel system is not necessary, but highly desirable, and is an example of the second category. [Ref.44:p.27]

Seven configurations were considered, capable of carrying between eight and 75 passengers. All were required to satisfy a short-haul range requirement of 600 nm. Of the seven configurations, three were "all new" designs, while four were MV-22 derivatives. [Ref.41] A summary of those initial designs, developed for the Phase I study, is as follows:

*a. All New Designs*

- \* The CTR-800, designed to carry 8 passengers, is the approximate size of the XV-15. Its size was seen as best supporting executive transport.
- \* The CTR-1900 carries 19, and is similar in appearance to some of the smallest commuter turboprops currently in use.
- \* The CTR-7500 is the largest configuration studied, capable of carrying 75 passengers, 5 abreast.

*b. MV-22 Derivatives*

- \* The CTR-22A, essentially an unmodified MV-22, was rejected because of the limitations imposed by its transmission and fuel range. Without

upgrade, the aircraft was incapable of meeting a major civil certification milestone eluded to earlier. This requirement calls for the ability to hover with one engine inoperative (OEI), and safely transition to takeoff. An addition desire was the ability to complete this evolution, and the 600 nms short-haul outer envelope. In order to accomplish this, additional consideration would have to be given to Instrument Flight Rules (IFR) fuel reserves.

- \* The CTR-22B, capable of transporting 31 passengers, is considered the "minimum change V-22". [Ref.41:p.19] It includes an upgraded transmission, and the basic amenities of small commercial aircraft (lavatory, galley, and baggage).
- \* The CTR-22C uses the MV-22 wing and propulsion system, but a unique fuselage. Without engine growth, it is capable of transporting 39 passengers, 3 abreast.
- \* The CTR-22D widens the CTR-22C's fuselage to accommodate four abreast, and a total capacity of 52 passengers. To satisfy the 600 nm range requirement necessitates engine growth of approximately 15%. [Ref.41]

"The design technology of the V-22 military tiltrotor drove the preliminary design of all the configurations." [Ref.41:p.11] Furthermore, "the structural design concept and propulsion systems used on all the configurations are the same as the V-22 military tiltrotor." [Ref.41:p.11]

Still, the Phase I study acknowledges that these configurations were developed primarily to facilitate the market research, and were not necessarily considered for actual development. "V-22 derivatives offer some market penetration, but new designs are required to meet full potential market." [Ref.41:p.12] The CTRDAC went even further in this regard. It was the committee's belief that "there is a general consensus that the

unique military capabilities built into the V-22 make it an unlikely candidate for a CTR, even in a modified form." [Ref.13:p.20]

### **3. The CTR2000**

"Military V-22 production cost experience has little direct comparability to manufacture of commercial tiltrotors". [Ref.44:p.18] "Commercial developments...tend to emphasize lower production costs, improved vehicle operational efficiencies, and increased aircraft availability with lower maintenance costs." [Ref.41:p.15]

Taking such considerations into account, "an entirely new CTR design will be necessary for the civil market." [Ref.13:p.23] These factors led manufacturers to work with NASA in their efforts to establish a "baseline design" for the CTR aircraft. This design incorporated what was believed to be the best available and ongoing technologies in 1994. [Ref.13:p.A-2]

Manufacturers went on to design a configuration that the CTRDAC utilized in their analysis and report to Congress [Ref.13:p.23]. The CTR2000 accommodates commercial manufacturing and operating realities. At the same time, it optimizes its seating capacity to target the short-haul passenger market. [Ref.13:p.23-24 and A-2]] The aircraft features room for 40 passengers, has a maximum gross vertical takeoff weight of 43,150 lbs, and can cruise at 315 knots [Ref.13:p.24].

#### **D. CTR DEPENDENCE ON MV-22 DEVELOPMENT AND TECHNOLOGY TRANSFER**

"Inevitably, tiltrotor development knowledge will benefit from the experience gained from...the two phases of V-22 development, the Full-Scale Development (FSD) and Engineering and Manufacturing Development (EMD)." [Ref.13:p.A-1] In fact, as pointed out by Roger Lacy and Joseph Wilkerson of Boeing's Helicopter Division, "as the V-22 development has progressed through Full Scale Development (FSD) and Engineering and Manufacturing Development (EMD) phases, promise of a viable CTR continue to grow." [Ref.46:p.2] Furthermore, "the V-22 will provide the basic, or core, tiltrotor technologies, including handling qualities, performance, dynamics, and stability." [Ref.13:p.A-3]

As opposed to a highly modified MV-22, it has previously been established that the CTR will likely be an "all new" design [Ref.13:p.23]. In order to accommodate passenger travel and amenities, commercial efficiencies, and FAA certification, key technologies must be adopted to the uniqueness of commercial operations. [Ref.13:p.A-3]

In regards to technology transfer between the MV-22 and the CTR, Colonel Bob Garner, MV-22 Program Manager raised some cautions. In an interview with the researcher, he explained that:

You have to be careful with the way you talk about these things. In one's mind, one needs to be able to separate the technology from the hardware. The technology is directly transferable. The hardware is probably not. [Ref.47]

NASA's Dr. Zuk adds, "yes, the V-22 has a lot of direct spinoffs." [Ref.48]

The CTRDAC claims that MV-22 operations cannot address these unique commercial advances. [Ref.13:p.A-5]. Still, a great deal can be learned in regards to these commercial design requirements by assessing where one is in terms of the development of related MV-22 technologies. MV-22 systems can provide baselines, and highlight the direction in which those technologies must be taken to derive commercial variations. Some baseline technologies can aid in the consideration of commercial certification requirements, operator and community acceptance, passenger comfort, and competitive economics. [Ref.13:p.A-3]

### **1. "Fiber Placement" Composite Manufacturing**

The most significant of the advanced technologies incorporated in the MV-22 is the extensive use of composites. "To date, no commercial aircraft has used more advanced composites than the V-22." [Ref.41:p.44] More significant, is its associated innovative composites manufacturing process called "fiber placement." [Ref.49] CTR manufacturers are certain to exploit this advance, should a final management decision select composite technology over aluminum. [Ref.13]

Increases in the use of composite materials in aircraft programs, and its associated high cost manufacturing processes, have led to the development of improved automatic manufacturing methods. The two most prevalent automated methods are filament winding and automated tape lay-up. However, both processes have limitations in their flexibility to work with certain aspects of contouring. [Ref.49:p.69]

Filament winding is best when dealing with circular cross sections or convexed surfaces. A continuous process, it is difficult to maintain ply thickness if the structure's contour changes. Subsequent machining to obtain the required thickness often becomes necessary. [Ref.49:p.69]

Automated tape lay-up works well with relatively simple contours. An automated tape-laying machine (ATLM) dispenses preimpregnated tape directly to the tool surface. However, it must conform to natural fiber paths. Any deviation will result in wrinkling of the tape. [Ref.49:p.69]

Boeing Helicopter's Lee Kitson and Brice Johnson, in a paper presented before the 1995 American Helicopter Society's annual forum, presented a new process for manufacturing composites called "fiber placement." They describe the process as "an innovative new technology which blends the best features of filament winding and automated tape lay-up." [Ref.49:p.70]

Fiber placement enables versatility in handling a wide variety of structure sizes and configurations. It combines speed, accuracy and repeatability; qualities not combined in either of the other two methods, yet expected in cost-effective, automated processes. [Ref.49:p.70]

"A fiber placement machine combines multiple preimpregnated fiber tows into a wide band for direct application to a tool surface at near zero tension." [Ref.49:p.70] Similar to filament winding, "material is deposited on to a rotating mandrel and the individual tows have the ability to pay out at different rates." [Ref.49:p.70] This allows

for changes in structural size and contour. Like automated tape lay-up, the roller remains in contact with the structure's surface.

The fiber placement process was first demonstrated by the Air Force Materials Lab, when Hercules Aerospace applied the process to three MV-22 aft fuselage sections for Boeing Helicopters. With its success, Boeing first realized the potential for applying this emerging process to other production activities. [Ref.49:p.70]

According to the CTRDAC, the primary issues in regards to a composite CTR, are "extended fatigue life and failure modes." [Ref.13:p.A-10] Before Government certification of a composite CTR will occur, "this concern must be dealt with accordingly." [Ref.13:p.A-10]

## **2. Manufacturing**

"The V-22 is the first major aircraft to be entirely computer designed." [Ref.2:p.54] Hand-in-hand with the leading edge work in the composites area, enormous strides are now being made in the Osprey program's application of digital technology to the design and manufacturing process. These technologies are commonly referred to as computer-aided design (CAD), and computer-aided manufacturing (CAM). [Ref.13:p.A-11]

Computer-Aided Three-Dimensional Interactive Application (CATIA), is being linked directly into aspects of manufacturing from design and development of tooling, to fabrication of components and structural elements. The entire structural development is controlled by a "digital sole authority data set." [Ref.13:p.A-11] A wealth of CTR

transferable knowledge "will be gained by examining how the MV-22 production experience progresses." [Ref.13:p.A-12]

### **3. Flight Control System**

According to the Phase II study, "significant redesign of the V-22 redundant digital fly-by-wire flight control system is not anticipated." To a degree, this is possible because the Interim Airworthiness Criteria (IAC) does not address fly-by-wire systems in great depth. [Ref.44:p.28] Although serving as a technology base in this regard, the MV-22 system operates without a mechanical backup, and FAA certification has generally required this "rudimentary mechanical" capability [Ref.13:p.A-5]. It is likely therefore, that the CTR will require same increased reliability through the addition of rudimentary redundancy. [Ref.13:p.A-6]

### **4. External Noise Reduction**

"V-22 data are needed to validate noise profiles for larger commercial tiltrotors." [Ref.44:p.35] In this regard, it may be more a matter of learning what not to transfer from the MV-22 to the CTR.

A great deal of tiltrotor noise generation is attributable to what is referred to as Blade Vortex Interaction (BVI). BVI is greatest during approach to landing, and is considerable in the MV-22 three-bladed rotor design. [Ref.13:p.A-14] As a result, the MV-22's noise profile "is on the borderline of meeting FAA/International Civil Aviation Organization (ICAO) requirements" when in the landing approach phase. [Ref.13:p.A-12]

Research and development of noise reduction technology is being headed by NASA. It includes the development of a four or five-bladed rotor system, as opposed to the three-bladed system used on the MV-22. [Ref.13:C-7] However, the CTRDAC points out that regardless of the redesign, a low noise rotor will not, in and of itself, be enough to satisfy the external noise goal of 12 dBA. [Ref.13:p.A-14]

The CTRDAC voiced critical concerns in regards to progress being made in noise reduction technology, "other than rotors." The committee felt that the level of funding precluded timely solutions that would support the results desired by the year 2005. [Ref.13:p.C-7]

Add to this, the fact that Title 49 USC, section 44715, now prohibits the FAA from issuing an original type certification if it finds "that the manufacturer has not incorporated all technically practicable and economically reasonable noise abatement technologies appropriate for the aircraft design." [Ref.13:p.C-8]

However, even if a CTR is technically within compliance, the Federal Aviation Regulations (FAR) point out, that this:

Is not to be construed as a Federal determination that the aircraft is acceptable from a noise standpoint in particular airport environments. Responsibility for determining the permissible noise levels of aircraft using an airport remains with the proprietor of the airport and surrounding community. [Ref.50:Part 36:p.1]

Couple these facts with the high probability that CTR operations will involve highly populated, city-center areas. The end result is that noise reduction becomes a critical CTR design consideration. [Ref.13:p.A-12 - A-13]

However, in addition to noise reduction technology, there are also operational techniques that can be used to abate noise in the vicinity of vertiports. [Ref.44:p.35] The CTRDAC refers to these techniques as "flight path management." [Ref.13:p.A-14]

Landing approach glidepath angle selection is an example. Because of its VTOL capability, a CTR can approach a vertiport at much steeper angles of decent, than can a turboprop. For fixed-wing aircraft, the standard glidepath is three degrees. Preliminary tests indicate the optimal CTR glidepath is somewhere in the vicinity of 9 to 12 degrees [Ref.44:p.42]. During flight simulation evaluations, Government and Industry test pilots actually preferred the 12 to 15 degree range. [Ref. 44:p.42]

This can have a significant impact in decreasing external noise levels through standard arrival procedures. As described in the CTRDAC's report, at one mile from touchdown, using a three degree glideslope, an aircraft is approximately 270 feet above ground level (AGL). Using a 9 degree glideslope on the other hand, increases that height to 800 AGL. [Ref.13:p.19]

The FAA is heavily involved in this area. In a telephonic interview with the FAA's Steve Fisher, he described how preparations are underway to standardize and certify CTR vertical flight terminal area procedures (VERTAPS). He was cautiously optimistic that some of this approach certification may eventually involve the MV-22. [Ref.51]

Both noise reduction technology and flight path management techniques will be integrated and tested aboard a modified MV-22, during Phase B of the technology demonstration program. [Ref.13:p.A-23 - A-25]

## **5. Internal Noise Reduction/Vibration Levels**

MV-22 development can provide relatively little technology transfer in these areas of concern. Very minor considerations were given to internal noise levels and passenger comfort since the aircraft was designed as a military transport. [Ref.13:p.A-15]

However, the Osprey does provide a beneficial starting point or baseline from which to engineer design improvements in the CTR. For example, the interior noise levels of most short-haul commuters is in the 75 to 85 DBA range. The Phase II study reveals that the "minimum change" CTR-22B can reduce noise levels to approximately 85 dBAs using approximately 500 lbs of active suppression devices, and passive insulation. It further explains that an additional 220 lbs would further reduce that level to 78 DBAS.

[Ref.41:p.34]

Significant reductions in vibratory loads can be realized as a by-product of reducing external noise levels. By adding additional rotor blades, improvements are achieved in both areas.

## **6. Contingency Power Requirements**

FAA regulations require that an aircraft possess the capability to either fly away, or hover and land, following a single engine failure. There are several options for providing an aircraft with this capability. [Ref.13:p.25]

First, one way to achieve this capability is to design-in excess shaft horsepower (SHP) in the engines. This is not considered cost effective, considering the added weight, fuel consumption, and operating costs, as compared to the high reliability levels and probability of engine failure. [Ref.13:p.25]

More likely, is to take advantage of the fact that turbine engines can be operated beyond their normal limits for short periods of time. Long term, this alternative can have cost impacts. However, they are considered more reasonable. This is so because the effects of operations above the normal range are cumulative, and reduce the engine's remaining service life. However, it is likely to be more cost effective to remove and replace an engine ahead of schedule, than to operate the aircraft at higher costs on a routine basis by carrying excess horsepower. [Ref.13:p.25]

The MV-22, like most military aircraft, has contingency power capability that takes advantage of this second option. The MV-22 however, must add additional OEI considerations unique to the rotor synchronization requirements of tiltrotors and tandem rotor helicopters. The CTRDAC recommends that "any prospective CTR should use an OEI contingency design similar to the X-15 an V-22." [Ref.13:p.A-7] "However, because the V-22 is a military aircraft, it is not required to meet the stringent FAA certification rules for commercial use." [Ref.13:p.A-6]

#### **E. ECONOMIC BENEFITS DERIVED FROM PRODUCTION OF THE MV-22**

Production of the MV-22 is scheduled to begin in 1997. Assuming a timely decision is reached, and production takes place as scheduled, a number of substantial

impacts should be felt. Some benefits are derived as a direct result of MV-22 production. Others are indirect, and based on an assumption that production of CTR derivatives are dependent on a predecessor military version for reasons previously described. A study done by the Department of Commerce, taking into account multiplier effects, concluded that the total increase in national economic activity as a result of CTR production could be as high as \$80 billion per 1,000 CTRs produced. [Ref.44:p.3] These benefits include such considerations as the balance of trade, the aircraft industrial base, and jobs. [Ref.2:p.47-48].

### **1. Balance of Trade**

Assuming that U.S. manufacturers maintain their seven to ten year lead over world competitors, initial CTRs will likely be produced in this country. Georgia Tech's McKeithan believed this could lead to "an entirely new segment of the aviation industry, dominated by the United States." [Ref.1:p.123]

During 1990 House testimony, Bell's Horner, using the Phase I study as his source, estimated total CTR exports could easily top \$10 billion [Ref.1:p.12]. The Phase II study estimated CTR exports could generate \$28 billion in the first ten years of production [Ref.44:p.3]. Based on 1994 dollars and a 20 year CTR production period, the CTRDAC puts that figure more conservatively at approximately \$17.8 billion [Ref.13:p.E-86].

### **2. Aircraft Industrial Base**

Clearly, the major recipients of the financial benefits of any program are the prime tier contractors...Companies that compose the middle tier of V-22 contractors also will benefit financially from the program...The largest

group of companies supporting the program is the lower tier, composed of subcontractors who supply the first two tiers with parts, materials, semifinished goods, and specialized services. This tier of suppliers consists of the most vulnerable and critical group of suppliers to the U.S. industrial base. [Ref.2:p.52-53]

It is estimated that perhaps as much as 1,000 companies will eventually be involved in the development and production of the MV-22. These companies will benefit directly from MV-22 production by supplying systems, components, materials, and services. [Ref.2:p.48]

Perhaps more significant, will be the indirect impact that MV-22 production has in contributing to the economic health of those companies who have a stake in production of the CTR. This is so, because many of the same companies involved in MV-22 production, will likely be involved in the production of civil derivatives. [Ref.2:p.49] In addition, there will likely be new entrants into the market, hoping to exploit a percentage of the increase in demand [Ref.2:p.63]. Developing the MV-22 will lead in turn to the development and production of new technologies and materials applicable to the CTR, further stabilizing employment, and enhancing skills in the civil aircraft industry.

[Ref.2:p.54]

### **3. Employment**

A third positive benefit of MV-22 production will be felt by the labor force. Development and production of the Osprey, will create a demand for workers with new skills, some unique to the tiltrotor technology. According to a CTR Industrial Base Impact study, depending on market demand, CTR sales could indirectly generate an additional

100,000 to 300,000 jobs over the course of the CTR's production period. [Ref.2:p.62]

The CTRDAC report points out that nearly all large turboprop aircraft that support the short-haul commercial market are manufactured in foreign countries. The report estimates that capturing the lower bound world market of 1,160 required CTRs, could indirectly generate and maintain a demand for an estimated 648,000 jobs during the 2007 to 2021 production period. [Ref.13;p. 79]

In an interview with Congressman Pete Geren, in easily understandable qualitative terms, the Congressman may have summed up best, what CTR spinoffs of the V-22 can equate to in overall economic terms. The Congressman argued that the "the V-22 has the potential to do for many parts of the country, what Boeing did for Seattle." [Ref.19]

#### **F. QUANTIFYING THE CTR's DEPENDENCE ON THE MV-22**

Finally, the question must be asked: Could the CTR still happen without Defense procurement of the MV-22? In 1990 Congressional testimony, when again, it appeared that the MV-22 program would not survive, Bell's Horner was asked that question. Specifically, he was asked whether cancellation of the MV-22 would "kill the CTR or postpone it? Horner, speaking on behalf of both Bell and Boeing, began his response by stating that such a predicament had already been studied. It was the manufacturers' belief that the CTR could still possibly happen, but that "you'd be looking at, at least a eight to ten year delay and probably longer." [Ref.1:p.128] Horner went on to describe how "it was very questionable as to whether or not the investment would still be worthwhile...without that stamp of approval." [Ref.1:p.127] The stamp of approval

Horner was referring to, seems to capture the essence of what the CTR derives from the operational experience the MV-22 can potentially provide.

#### **G. SUMMARY**

This chapter has identified and analyzed the key dependencies that exist between the MV-22, and potential CTR derivatives. Some dependencies, such as the use of the MV-22 as a technology demonstrator provide a clear and more tangible example. Other dependencies such as those resulting in commercial variations of specific tiltrotor technologies may be somewhat more subtle.

Still, regardless of the seemingly insignificance of any one or several dependencies, it is questionable as Bell's Horner pointed out, as to whether the CTR could happen without their collective influence. [Ref.1:p.128]

The final chapter will draw conclusions, addressing the primary and subsidiary research questions.



## VI. CONCLUSIONS

This chapter summarizes the research effort and provides conclusions by answering both the primary and subsidiary research questions.

### A. PRIMARY RESEARCH QUESTION

**Are potential CTR applications dependent on Defense development and procurement of the MV-22 Osprey, and if so, to what extent?**

The answer to this question is clearly yes. In regards to what extent, Dr. Zuk of NASA Ames phrased it best. Zuk argued that the MV-22 "is necessary, but not sufficient." [Ref.48] A detailed discussion of the contributing factors to this dependence was provided in Chapter V.

Agreement is nearly unanimous that this dependence is related to two key contributions provided by the MV-22. The first contribution will be gained through technology demonstration and operational experience, once the Osprey is fielded. [Refs.1, 13, 19, 41, 43, 44 and 45]. The second contribution is based on the general tiltrotor knowledge, and technology transfer that is gained from the R&D, design, manufacturing, and production of the Osprey [Refs.1, 13, 41, 43, 44, 46, 47 and 48].

The American aviation industry currently maintains a slight lead over world competitors in the race to field a civil tiltrotor. [Ref.13] Continued progress towards fielding a CTR first, depends on gaining operational experience and data from a military derivative. Through its demonstrated reliability, safety and enhanced capabilities over other

transportation modes, the MV-22 can build confidence in the potential of tiltrotor technology. More specifically, it becomes the catalyst for gaining more widespread civil acceptance by potential investors, operators and the traveling public. [Refs.1, 13, 19, 43 and 45]

Colonel Garner believes tiltrotor technology has progressed sufficiently, to the point that manufacturers could build the CTR right now [Ref.47]. Congressman Weldon agrees. However, he feels it is questionable as to whether potential operators can be enticed to purchase it without demonstrated operational experience [Ref.3].

During the course of this investigation, a more serious issue concerning introduction of a CTR was uncovered. The reader will recall that in proving the tiltrotor's potential worth, the interim use of a V-22 derivative, as part of a technology demonstration program, is thought to be essential. This is particularly relevant to the short-haul commercial passenger market. [Refs.1, 13, 41, 44 and 45] Here, as NASA's Rosen described it, a "systems or systems integration problem" exists. [Ref.1] Or as the researcher described it, a Catch 22 dilemma. Here, independent entities have exclusive control over various resources and decisions. Each consideration effects the entire tiltrotor "system," particularly the implementation of a supporting infrastructure. [Ref.1]

A complex coalition of these interests must be formed. These interests must be convinced or enticed, to commit their resources and decision-making capability, if the tiltrotor system is ever going to come to fruition. The Government is being urged to provide the necessary leadership and financial assistance. This is to be done concurrently with what the MV-22 Osprey provides. Only then, can the systems integration problem be overcome.

[Refs.1, 13, 41 and 44] Most important, in trying to bring the CTR to market, overcoming the systems integration problem, and establishment of the supporting infrastructure are more critical than the MV-22 [Refs. 1, 13, 41 and 44].

The lack of available infrastructure brings to mind a useful analogy. In order to grasp the complexity of this problem, one should consider the following scenario:

How easy would it have been 90 years ago, for aircraft manufacturers to convince potential investors to obligate their resources to purchase a fleet of revolutionary new aircraft? Now, consider that this same aircraft would require the support of hard-surface, 10,000 foot runways. It is doubtful that those investors could have been persuaded to invest.

## **B. SUBSIDIARY RESEARCH QUESTIONS**

Seven subsidiary research questions were initially defined. Answers to each of those questions are as follows:

### **1. Is there an historic commercial aviation dependence on Defense aviation research and development efforts?**

As noted in Chapter II, the Department of Defense has served as contributor and precursor to a great deal of the evolution that has taken place in the civil aviation arena. Revolutionary aviation developments, such as the jet aircraft and helicopter, first came to fruition in military aircraft designs. Advances such as these have ultimately evolved and been exploited through commercial and/or civil operational use. [Ref.5]

The most pronounced technological leaps in civil aviation have been dependent upon initial progress being made in development of military derivatives of those technologies. Most major advances in aviation have had a military technological precursor. [Ref.1]

**2. What are the historical barriers to commercial aviation innovation, and to what extent have these barriers been influenced by past Defense aviation development efforts?**

It is not the aircraft manufacturers who have exploited aircraft technologies, but rather operators and commercial carriers. [Refs.1 and 6] Furthermore, without the potential for profit, the commercial exploitation and application of innovative aviation technologies would be unlikely to occur. [Ref.5]

As presented in Chapter II, there are three general barriers to the commercial innovation of new aviation technologies. They are the public's willingness to accept the new technologies, and the willingness of manufacturers and operators to assume the technical and financial risks associated with development and fielding. [Refs.1, 2, 5 and 9] There are two additional barriers that, in the past, pertained to utilization of the helicopter in the short-haul transportation market. They were the lack of a supporting infrastructure, and a consensus building coalition. [Refs.2 and 20]

These barriers have been influenced to a great extent by two major contributions made by the Defense Department. One conscious or direct contribution has been the Defense Department's leadership in research and development. It is primarily associated with the

willingness of the Defense Department to pay a major percentage of the development costs, in proving new aviation concepts technically feasible.

Inadvertently or indirectly, the Defense Department has had some effect on these barriers by providing operational experience in a military derivative of a particular aviation technology. [Refs.2 and 5]

Aviation research and development has been comprised of just as many designs that were never fully developed, or ended in failed attempts, as opposed to successful innovations. Aircraft manufacturers and potential operators are all keenly aware of this. As a result, private investors have shown a general unwillingness to take the lead in innovative aviation technological development. Most research and development efforts associated with radical leaps in aviation technology have been lead and funded by Government efforts. [Ref.17]

The Defense Department has funded numerous demonstration programs for the long term study of high risk technologies, prior to making a commitment to manufacture aircraft employing such technologies. Following through with production of military variants of an aviation concept also provides the demonstration through operational use. Demonstration is often a key factor in gaining the confidence and commitment from potential operators. [Refs.1, 13, 41 and 44]

Finally, gaining operational experience is ultimately necessary to prove a technology's commercial potential. This provides the operator with valuable usage data, as well as tends to mitigate the risk potential to the traveling customer. [Ref.1]

**3. Is there market potential for CTR applications, and if so, in what areas do these markets lie?**

According to a series of market studies conducted over the last ten years and summarized in Chapter IV, there is a world wide market for approximately 1160 - 1600 CTRs. In the following categories there is a market for approximately 75 - 150. [Ref.13]

- \* Corporate/Executive Travel - Most Fortune 500 companies operate a number of aircraft for their top executives and leading customers.
- \* Civil/Public Applications - This umbrella category includes such areas as drug enforcement, Coast Guard, border patrol, police, fire, disaster relief, and medical transport.
- \* Offshore Oil/ Resource Development
- \* Cargo/Package Express - Package express service continues to grow. However, operations are beginning to experience difficulty in getting packages from the pickup point to departure airports because of the ground congestion. [Ref.1]

The market that possesses the greatest potential is the short-haul commercial passenger market. World demand estimates for CTRs range from 1085 - 1450. [Ref.13]

Demand is considered high predominantly for two interrelated reasons. First, it is now more common for people to fly, and most are flying relatively short distances. As a result, the country is experiencing major problems with the current and future capacity of our commercial aviation transportation system. [Refs.1, 41, 43 and 44] This is not a unique American problem. Many countries in Europe and also Japan face similar capacity dilemmas.

Second, the tiltrotor is envisioned to be most advantageous in the range within which, the current short-haul carriers, shown to be the root cause of the congestion problem operate.

The tiltrotor's solution to such congestion lies in its ability to eliminate the use of airports all together for a majority of short-haul traffic. A network or series of vertiports would be used. [Refs.1, 41, 43 and 44]

The world's only manufacturers with previous tiltrotor experience are Bell and Boeing of the U.S. Both have entered a partnership to produce a CTR by the year 2007. The Bell - Boeing team maintains a slight lead over the remaining world competitors, who's only serious contenders include a consortium of three European countries, and in the past, the Japanese. Russia is a distant fourth, and unlikely competitive. [Ref.1 and 13]

#### **4. What are the barriers to commercial innovation of the tiltrotor concept?**

There are five barriers to commercial innovation of the tiltrotor. To varying degrees, all must be addressed in order to successfully field the CTR. Four barriers were identified in the tiltrotor market studies. Three of these same four barriers, were also identified in Chapter II, as being historical in nature. The three are public acceptance, technical risks, and financial risks. [Refs.1, 2, 5 and 9] The fourth identified in the market research is the lack of a supporting tiltrotor infrastructure [Refs.1, 13, 41 and 44]. A fifth barrier, believed by many to be the most significant, is a systems integration problem [Ref.1].

Both the experts and the research agree that the most critical steps in overcoming these barriers, particularly the systems integration barrier, are the formation of public/private partnership led by the government, and the implementation of a technology demonstration program. [Refs.1, 13, 41 and 44]

**5. Has previous Defense involvement in tiltrotor research and development (other than the MV-22), had any influence in overcoming the barriers associated with the CTR, and if so, to what extent?**

Development of the Transcendental Model 1-G began as early as 1945. Later, a great deal of the research surrounding this aircraft was accomplished under joint Army - Air Force sponsorship. First achieving free flight on 6 July 1954, it later accomplished a 70 percent conversion from the helicopter mode to the airplane mode. [Refs.23 and 24]

The Bell XV-3 proposal was a continuation of the Model 1-G tiltrotor. It was again sponsored by the Army and Air Force. Built in 1955, it was intended to provide design and test data for the development of follow-on tiltrotor aircraft. The XV-3 made its first complete conversion from the helicopter mode to cruise flight on 17 December 1958.

This accomplishment and further XV-3 testing established the tiltrotor concept as being technically feasible, though inherent technical problems with the tiltrotor technology still remained. [Refs.23, 24, 27, 28, 28, 29, 30 and 31]

The XV-15 was developed under a NASA/Army/Bell research program as a tiltrotor concept demonstrator. It accomplished its first free hover on 3 May 1977. The first in-flight full conversion was achieved on 24 July of that same year. The full conversion was significant in advancing the tiltrotor concept. [Ref.24]

The XV-15 was not intended for operational use. [Ref.34] However, in addition to serving as a technology demonstrator, the XV-15 provided a "link" between its predecessors, that had proven the tiltrotor concept feasible, and a potential production aircraft. The XV-15

contributed to gaining both operator and public acceptance of the tiltrotor concept through its guest-pilot program and flight demonstration tour. [Ref.24]

The three historical barriers addressed in Chapter II (public acceptance, technical risk, and financial risk) were influenced by the following three contributions:

- \* Government leadership and funding of tiltrotor research and development.
- \* Proving the tiltrotor concept technically feasible.
- \* Providing tiltrotor technology demonstration. [Refs.24 and 28]

These previous efforts had no influence in addressing the barriers effecting introduction of the helicopter into the short-haul passenger market [Refs.2 and 20].

#### **6. Will Defense development efforts involving the MV-22 help influence any of the barriers associated with the CTR, and if so, to what extent?**

If the civil tiltrotor follows the classic progression that other new and innovative aviation concepts have, then it will likely be developed only after several years of MV-22 operational experience. [Ref.1] As discussed in Chapter II, the belief that the military must serve as the proving grounds for new aviation concepts is not new. [Refs.1, 2, 5, 12, 13, 19, 44 and 45]

It is believed that the Osprey may contribute to proving the tiltrotor concept by demonstrated success [Ref.44]. Through operational flying, potential operators gain valuable general knowledge, as well as operational, reliability, maintainability, and safety data [Ref.45]. This information is deemed critical in order to judge whether a commercial derivative of the

tiltrotor has the potential for economic viability [Ref.1]. Above all, operational experience helps reduce the uncertainties for potential civil users [Ref.1]. MV-22 aircraft are expected to have accumulated approximately 60,000 flight hours, two years prior to the projected CTR production start [Ref.13].

As of yet, no representative CTR prototype exists. The four CTR market studies, agency representatives, and individual experts, all recommend that the CTR be preceded by a interim technology demonstration program using the MV-22, in either its military configuration, or a highly modified civilianized version. The demonstration program is viewed as essential in order to gain community acceptance, particularly in the areas of noise and safety. [Refs.1, 13, 41 and 45]

Several commercially unique technological advances were mentioned as not being addressed by gaining operational experience in the MV-22. They include external and internal noise reduction. [Ref.13] The researcher however, believes that these commercial advances can be mitigated to varying degrees, through development of the MV-22.

It is believed that a MV-22 demonstration program will also aid infrastructure development, by enabling the establishment of a start-up network of vertiports. This will minimize initial investment, while still demonstrating how a CTR system can work. [Ref.13]

**7. Are there any other benefits that potential CTR applications are gaining, or likely to gain from Defense development and procurement of the MV-22?**

No commercial aircraft has used more composites than the MV-22 [Ref.41]. More significant, is its associated innovative composites manufacturing process, called fiber

placement [Ref.49]. CTR manufacturers are certain to exploit this advance, should a final management decision select composite technology over aluminum [Ref.13].

The MV-22 is the first major aircraft program to use computer aided design in its entirety. [Ref.2] The program makes use of Computer-Aided Three-Dimensional Interactive Application (CATIA) [Ref.13]. CTR development would most likely use this technology in its design as well.

Substantial redesign of the V-22 redundant digital fly-by-wire flight control system is not believed to be necessary. However, the MV-22 system operates without a mechanical backup, and FAA certification has generally required this capability. [Ref.44]

The MV-22 is needed to validate noise profiles for larger commercial tiltrotors. Noise associated with the MV-22 during the landing phase is considerable. This is primarily due to its three-bladed rotor design. Research and development of noise reduction technology includes the development of a four or five-bladed rotor system, as opposed to the three-bladed system used on the MV-22. External noise reduction is a critical CTR design consideration. [Refs.13 and 44]

Operational techniques to reduce noise levels can also be employed. A CTR can approach a vertiport at much steeper angles of decent, than can a turboprop. Preliminary tests indicate the optimal CTR glidepath is somewhere in the vicinity of 9 to 12 degrees for the tiltrotor, as opposed to 3 for a turboprop. This can have a significant impact in decreasing external noise levels through standard arrival procedures. [Refs.13 and 44] The FAA is

heavily involved in this area. There is hope that some of this work may eventually involve the MV-22. [Ref.49]

MV-22 development can provide relatively little technology transfer in the area of internal noise reduction [Ref.13]. However, the Osprey provides a baseline from which to engineer design improvements in the CTR [Ref.41].

There are several options for providing an aircraft with FAA one engine inoperative (OEI) capability. One way to achieve this capability is to design-in excess shaft horsepower (SHP) in the engines. This is not considered cost effective, considering the added weight, fuel consumption, and operating costs. The second option is based on the fact that turbine engines can be operated beyond their normal limits for short periods of time. The MV-22, like most military aircraft, has contingency power capability that takes advantage of this second option. The CTRDAC recommends that the CTR should use an OEI contingency design similar to the MV-22. [Ref.13]

Assuming that U.S. manufacturers maintain their seven to ten year lead over world competitors, CTRs being produced in this country could lead to a segment of the world's aviation industry, being dominated by the U.S. [Ref.2]

It is estimated that perhaps as much as 1,000 companies will eventually be involved in the development and production of the MV-22. Many of the same companies involved in MV-22 production, will likely be involved in the production of civil derivatives. [Ref.2]

Development and production of the Osprey will create a demand for workers with new skills, some unique to the tiltrotor technology. Depending on market demand, CTR sales

could indirectly generate 100,000 to 300,000 jobs over the course of the CTR's production period. [Ref.2]

An additional economic benefit from MV-22 production, according to Colonel Garner, will be gained by the manufacturers. Revenue generated by the Osprey, will be used to defray the costs of CTR development. [Ref.47]

## **C. SIGNIFICANT LESSONS LEARNED**

### **1. The CTR Employs Unique Commercial Systems**

It is apparent that there is a substantial difference between military tiltrotor specifications, and commercial requirements. The CTR's dependence on the MV-22 is therefore, far more dependent on "technology transfer," as opposed to systems or hardware transfer.

### **2. Infrastructure is More Critical Than MV-22**

Failure to produce the MV-22 will not eliminate the CTR's arrival, only slow it. Tiltrotor technology and corporate knowledge have progressed to the point where a CTR program can sustain itself. Without a favorable production decision, the pre-production MV-22 prototypes will still serve as technology demonstrators. What will be missing is the valuable operational and maintenance data that would be gained from operational experience.

However, trying to entice commercial carriers to invest in literally thousands of tiltrotor aircraft without the advantage of supporting infrastructure, is like asking potential carriers of 90 years past, to invest in aircraft that require hard-surface, 10,000 foot runways, when none existed.

### **3. The CTR Should Not Compete With Fixed-Wing Commuters**

There is no advantage in competing the CTR head-to-head with fixed-wing commuters. There is conflicting data concerning the ability to keep control of operating costs. It may be possible to minimize fuel consumption by optimizing the CTR's flight profile. For example, being able to depart from vertiports in the STOL mode may reduce fuel consumption by over 50%. Additionally, the CTR's maintenance costs are higher. Most significant, if these factors hold true, it will require as much as a 25% to 50% premium on airfares. Operated in the same environment as the fixed-wing commuter (airport to airport) the CTR offers the customer no advantage, with higher airfares.

In order to be profitable, the CTR must be operated in a manner that permits full exploitation of its unique capability. The tiltrotor's real advantage lies in its ability to eliminate the use of airports all together. The tiltrotor is both more efficient and effective in accomplishing intra-city travel as compared to inter-modal transportation methods. Market studies show travelers to have a value for time savings and convenience, thus permitting premium airfares.

### **D. RECOMMENDATION FOR FUTURE STUDY**

The barriers associated with the lack of supporting infrastructure and systems integration were similarly experienced during attempts to introduce the helicopter into the short-haul commercial passenger market. In the case of the helicopter, those attempts failed. Further study and analysis as to how these barriers might be overcome in the case of the CTR, could derive significant benefits for the nation's air transportation system.

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## APPENDIX A. TILTROTOR CHRONOLOGY AND SIGNIFICANT EVENTS

TRANSCENDENTAL AIRCRAFT CO. FORMED	1945
TRANSCENDENTAL AWARDED AIR FORCE CONTRACT	1951
TRANSCENDENTAL MODEL 1-G FIRST FLIGHT	6 JUL 1954
TRANSCENDENTAL MODEL 1-G CRASHES INTO	20 JUL 1955
DELAWARE. A/C HAD ATTAINED 70% CONVERSION XV-3 1ST ROLLOUT UNDER ARMY/AIR FORCE CONTRACT	10 FEB 1955
XV-3 FIRST FLIGHT	11 AUG 1955
XV-3 CRASH	OCT 1955?
XV-3 FIRST FULL CONVERSION	17 DEC 1958
XV-15 CONTRACT AWARDED	1972
XV-15 FIRST ROLLOUT A/C#1	22 OCT 1976
XV-15 FIRST FLIGHT	3 MAY 1977
XV-15 A/C#2 ROLLOUT	JUL 1978
XV-15 FIRST FULL CONVERSION	24 JUL 1978
JVX PROGRAM MANAGER ASSIGNED	JUN 1981
JVX MILESTONE 0	31 DEC 1981
XV-15 LANDING AT U.S. CAPITAL	25 APR 1992
ARMY, NAVY, AND AIR FORCE SIGN MOU DESIGNATING	JUN 1982
ARMY AS EXECUTIVE SERVICE FOR JVX JVX MILESTONE	8 DEC 1982

JVX PRELIMINARY DESIGN CONTRACT AWARDED	APR 1983
ARMY WITHDRAWS FROM JVX PROGRAM	MAY 1983
MARINE CORPS DESIGNATED EXECUTIVE SERVICE JVX DESIGNATED V-22 OSPREY	JAN 1985
V-22 JSOR APPROVED	APR 1985
V-22 MILESTONE II	1 MAY 1986
V-22 FSD CONTRACT AWARD (FPIF)	2 MAY 1986
V-22 ENGINE DEVELOPMENT CONTRACT AWARDED TO ALLISON	MAY 1986
PHASE I TILTROTOR STUDY COMPLETED	JUL 1987
CTR INDUSTRIAL BASE IMPACT STUDY COMPLETED	APR 1988
V-22 OSPREY ROLLOUT AT BELL	23 MAY 1988
V-22 ENGINE PRODUCTION CONTRACT AWARDED	JAN 1989
V-22 A/C#1 FIRST FLIGHT IN HELO MODE	19 MAR 1989
SECDEF CANCELS V-22 PROGRAM	19 APR 1989
NAVY RECLAMA	APR 1989
CONGRESSIONAL RESOLUTION REINSTATES PROGRAM	APR 1989
V-22 A/C#2 FIRST FLIGHT	9 AUG 1989
V-22 FIRST FULL CONVERSION A/C#1	14 SEP 1989
V-22 FIRST FLIGHT A/C#4	21 DEC 1989
V-22 FIRST FLIGHT A/C#3	8 MAY 1990
V-22 SHIPBOARD COMPATIBILITY TESTS	4-7 DEC 1990

PHASE II TILTROTOR STUDY COMPLETED	FEB 1991
V-22 FIRST MISHAP A/C#5 ON T/O WILMINGTON, DEL	11 JUN 1991
V-22 SECOND MISHAP A/C#4 ON ARRIVAL QUANTICO, VA, FLIGHT TESTS TERMINATED	20 JUN 1992
SECDEF PROPOSES NEW VERSION OF V-22 PROGRAM	JUL 1992
SECNAV APPROVES NEW EMD	SEP 1992
CONGRESS DIRECTS FORMATION OF CTRDAC	OCT 1992
V-22 AIRFRAME EMD CONTRACT AWARDED	22 OCT 1992
V-22 ENGINE EMD CONTRACT AWARDED	DEC 1992
V-22 GROUND TESTS RESUME	JAN 1993
V-22 FLIGHT TESTS RESUME	APR 1993
TILTROTOR EUROSTUDY EXECSUM COMPLETED	1994
V-22 JROC	AUG 1994
V-22 MILESTONE II PLUS (DAB REVIEW)	13 SEP 1994
V-22 ADM	10 FEB 1995
CTRDAC REPORT TO CONGRESS COMPLETED	DEC 1995
V-22 LRIP #1 APPROVED	7 FEB 1996



## APPENDIX B. SUMMARY OF CTR MARKET STUDIES

### 1. Civil Tiltrotor Missions and Applications - Phase I

#### Findings:

##### National Issues

\* MV-22 technology addresses several national issues:

1. U.S. prominence in tiltrotor technology.
2. Airport congestion relief.
3. Technical and industrial competitiveness.
4. Balance of trade.

##### Market Summary

\* The civil tiltrotor has large market potential, particularly in the short-haul passenger market.

\* Tiltrotor is superior to multi-engine helicopters under most conditions:

1. Twice the speed and longer range.
2. Lower operating costs.
3. Better community acceptance.
4. Better passenger comfort.

\* Tiltrotor is competitive with fixed-wing aircraft under certain conditions:

1. VTOL capability and time savings are key to success.

2. Greater convenience could result in capture of up to two thirds of short-haul markets.

\* Market penetration depends on aircraft configuration, economics and size. Assessment is difficult. Will require:

1. 300-1400 all new, unique civil designs.

2. 50-700 MV-22 derivatives with some civil modifications.

\* Primary market is in North America (65%-75%).

### Technical Summary

\* Six configurations analyzed from 8 to 75 passenger capacity:

1. Includes MV-22 derivatives and all new designs.

2. All designs based on MV-22 technology.

\* MV-22 derivatives with pressurized fuselages can accommodate 50 passengers and meet range objectives of 600 nautical miles (NM).

\* Passenger and community acceptance is anticipated.

\* Tiltrotors can operate in current airspace; however improvements are needed to exploit tiltrotor capabilities.

\* Early development of aircraft certification criteria is a priority. [Ref.41]

### Potential Barriers and Issues:

\* Technical validation.

1. Composite fuselage.

2. Pressurized cabin.

3. Aerodynamic improvement.
4. High performance configurations.

\* Certification validation.

\* Infrastructure.

1. Vertiport design, location, availability.
2. Adaptation into National Aviation System.

\* Operational characteristics.

1. Route proving.

\* Marketing.

1. Public perception and acceptance.
2. Safety.
3. Economic competitiveness.
4. Development of supporting infrastructure. [Ref.41]

### **Recommendations:**

#### **Civil Tiltrotor Technology Development**

- \* Reduce risks and costs through design concepts, materials, and production methods.
- \* Optimize aerodynamics and configurations.
- \* Validate key technologies.
  1. Canard configuration.
  2. Pressurized composite configuration.
  3. Rotor/wing interaction.

### Infrastructure Planning and Development

- \* Vertiports conveniently located in metropolitan areas.
- \* New terminal instrument procedures to take advantage of precision navigation equipment.
- \* Integration into the National Aerospace System.
- \* Certification criteria for powered lift.
  1. Continued development of airworthiness criteria.

### Flight Technology Demonstration Plan

- \* Identify key technologies.
- \* Identify vehicle candidates.
- \* Support certification criteria
- \* Define relationship to infrastructure needs.
- \* Develop financial options and schedule.

### Near-Term Actions

- \* Continue FAA/NASA/DOD/Industry cooperation for civil tiltrotor development.
  1. Follow-on work on civil tiltrotor technology development.
  2. Work on infrastructure and flight demonstration development plans.
- \* Key civil tiltrotor development to MV-22 program. [Ref.41]

## **2. Civil Tiltrotor Missions and Applications Phase II**

### **Findings:**

#### **National Issues**

\* Commercial tiltrotors could ease congestion and extend the useful life of existing airports.

1. Increase airport capacity by freeing runways and approach slots.
2. Network of vertiports could divert short-haul travelers away from airports all together.
3. Postpone or eliminate need for airport expansion.

#### **Market Summary**

\* Strong potential in short-haul market.

1. Tiltrotor is economically competitive.
2. Half of commercial service is under 500 nm.
3. By the year 2000 could create global demand for more than 2600 aircraft.  
Half would be in exports.

#### **Technical Summary**

\* A commercial tiltrotor is technically feasible.

1. Market responsive aircraft can be built.
2. Aircraft could be made available by the year 2000.
3. Turn-of-century commercial variant would be based on research and experience gained in designing, building, testing, and producing the military MV-22. [Ref.44]

### **Potential Barriers and Issues:**

\* Technology.

1. Validation for commercial applications.
2. Actual aircraft development.

\* Aircraft alone not sufficient. Need air/ground infrastructure.

1. Adaptation of air traffic control system.
2. Creation of vertiport network.

\* Operators/Travelers demand technology be proven:

1. Safe.
2. Efficient.
3. Environmental impact.
4. Human factors-based pilot considerations.

\* National Acknowledgment.

1. Endorsement as solution to congestion problem.
2. National leadership [Ref.44]

### **Recommendations:** (Specific Actions)

#### **General**

- \* Formation of public-private partnership to pursue national tiltrotor plan.
- \* Department of Transportation to lead.
- \* Continue NASA/FAA/Industry cooperation.

NASA

\* Develop commercial tiltrotor technology based on:

1. Environmental constraints.
2. Pilot-aircraft interface.
3. Vertiport Terminal Area Procedures. (VERTAPS)

\* Sponsor Technology Demonstration Program using:

1. MV-22.
2. Upgraded XV-15.
3. Simulators.

\* Risk and cost reduction through:

1. Improved materials.
2. Improved design.
3. Research to optimize technology for civil requirements.

FAA

\* Develop operational standards for:

1. Community noise.
2. Pilot-aircraft interface.
3. Develop VERTAPS.

\* Ensure National Airspace System enroute handling capability.

\* Advocate and support Technology Demonstration Program.

\* Provide initial, key, vertiport study grants.

- \* Expedite acquisition of MV-22 engineering test data. [Ref.44]

### **3. "Eurostudy"; A European Regional Transportation Study.**

#### **Findings:**

##### **Regional Issues**

- \* Europe's transportation infrastructure is overloaded.
  1. Road, rail, and air, all suffer from congestion.
  2. For aviation, improvements in ATC can increase enroute efficiency.
  3. No Airport congestion solution as of yet.
  4. Environmental concerns and political process slow potential solutions.

##### **Market Summary**

- \* Potentially substantial demand.
  1. Market for 116 cities studied. Potential ranges from minor to substantial.
  2. Highly fare sensitive. Tradeoff between cost and value for time savings.
  3. Location of vertiports defines success.
- \* Can compliment European rail market.
- \* Non-conventional markets (not currently served by European air or rail could add to demand).
- \* Increased air access for many communities.

##### **Technical Summary**

- \* Tiltrotor system is technically feasible.
  1. Military MV-22 provides technology base.

- \* Infrastructure components need to precede or accompany aircraft development.
- \* Required number of aircraft dependent on fare competitiveness relative to conventional air travel.
  1. 1226 CTRs required by year 2010 for even fares.
  2. Only 420 required at 25% premium. [Ref.45]

#### **Potential Barriers or Issues:**

- \* Required infrastructure action is a political issue.
  1. U.S. manufacturers are limited in ability to suggest European leadership.
- \* Paradigm shift in Europe.
  1. Heavy reliance belief in rail system.
- \* Civil acceptance awaits military operational experience.
  1. MV-22 as technology base.
  2. Safety.
  3. Reliability [Ref.45]

#### **Recommendations:**

- \* Industry and European Government cooperation.
- \* A demonstration program may be needed. [Ref.45]

#### **4. Civil Tiltrotor Development Advisory Committee (CTRDAC); Report to Congress.**

#### **Findings:**

##### **National Issues**

\* CTR could produce significant societal benefits.

1. Reduce airport congestion.
2. Create jobs.
3. Positive impact on balance of trade.

### Market Summary

\* A CTR system could be economically viable under certain assumptions.

1. Profitable without Government subsidies in heavily traveled corridors.
2. Significant numbers of travelers have a value for time savings and convenience; willing to pay a premium.
3. Vertiport location is critical success factor.

### Technical Summary

\* CTR is technically feasible. Industry production dependent on:

1. Additional research and development.
2. Infrastructure planning. [Ref.13]

### Potential Barriers and Issues:

\* Public/User (carriers) Acceptance

1. Aircraft noise levels.
2. Safety, Reliability.
3. Demonstration aircraft/program
4. Adequate level of infrastructure support

\* Technical Risks

1. Aircraft noise levels.

2. Aircraft certification
3. Technology validation

\* Financial Risks

1. High capital and operating costs in order to meet certification and regulations.
2. Manufacturing costs based on anticipated efficiencies.
3. Tiltrotor airfares in comparison to conventional airfares and competitive response.
4. Start-up costs due to certification, training, operational break-in inefficiencies.
5. Variability in demand forecasting.
6. Variation in rider utilization due to business travel fluctuation.
7. Estimated break even total sales low risk as compared to world-wide market demand.
8. Compound risks could jeopardize system implementation.

\* Infrastructure

1. Vertiport siting is critical.
2. Vertiport availability.
3. Requires demonstration aircraft/program.
4. Delays effect potential investment.

\* Systems Integration

1. No one agency controls the resources necessary for CTR system development.

2. Decisions to manufacture CTRs, develop air/ground infrastructure, and operate services are interdependent. [Ref.13]

**Recommendations:**

\* Creation of public/private partnership to coordinate all issues pertaining to CTR transportation system.

1. FAA take lead in coordinating activities.

2. Establish overall plan.

3. Minimize capital expenditures until production commitment.

4. Conduct periodic re-evaluation of plan.

\* Demonstration program for the purposes of:

1. Assess community/operator acceptance.

2. Assess environmental impacts.

3. Gain operational experience.

\* Develop vertiport network study for one promising region.

1. Include local government.

2. Begin preliminary planning and site identification for vertiports.

3. Conduct travel demand analysis

\* Proceed with an integrated, 10 year, CTR aircraft and infrastructure program. (research, development, test, and demonstration)

1. Cost sharing of \$600 million research and development between Government and industry.

2. A milestone process to account for program prognosis, capable of acceleration or termination as warranted.

\* Tiltrotor specific research complete by 2003 related to:

1. Low-noise rotor design.
2. Operational flight procedures to reduce noise.
3. Development of metrics and tools for assessing noise levels and community acceptance.
4. Contingency power demands on engine and transmission. (single engine operations)
5. Power-off control and landing capability.
6. Tiltrotor unique systems monitoring capability.
7. Flight deck human factors design.
8. Rotorwash and wake vortex assessment.
9. Internal aircraft noise.

\* General aeronautical research of importance to the CTR:

1. Composites, and in particular, manufacturing techniques.
2. Icing prevention/removal systems.
3. Fly-by-wire technology; failure modes and certification.

\* \$28 million in infrastructure specific research complete by 2003.

1. CTR ATC procedures.
2. Designing and implementing vertiport area airspace.
3. CTR Terminal Instrument Procedures (TERPS).

\* Continue and accelerate work on regulatory and certification issues.

- \* Department of Transportation (DOT) should conduct study of multi-modal operations to increase intercity transport capacity.
  1. Include CTR transportation system as contributing option in analysis.
- \* Flight test program for the purpose of:
  1. Verify noise reduction efforts. [Ref.13]

## APPENDIX C. LIST OF PERSONNEL INTERVIEWED

1. Mr. Steve Barlage, Manager, Civil Tiltrotor Business Development, Helicopters Division, Boeing Defense & Space Group, Interview by phone, 29 September 1995.
2. Dr. John Zuk, Civil Tiltrotor Program Office, Code APT, NASA Ames Research Center, Interview, 20 October 1995.
3. Mr. Steve Fisher, FAA Representative, Vertical Flight Terminal Area Procedures (VERTAPS), Interview by phone, 12 January 1996.
4. Colonel Bob Garner, Program Manager, MV-22 Program, PMA-275, Naval Air Systems Command (NAVAIR), Interview by phone, 19 January 1996.
5. Brigadier General Robert Magnus, USMC, Assistant Deputy Chief of Staff for Aviation, Code AP, Headquarters, U.S. Marine Corps, and Member, CTR Development Advisory Committee, Interview by phone, 26 January 1996.
6. Mr. Tom Archer, Federal Aviation Administration (FAA), Rotorcraft Certification Directorate, Interview by phone, 26 January 1996.
7. Representative Pete Geren, Democrat, Texas, Interview by phone, 9 February 1996.
8. Representative Curt Weldon, Democrat, Pennsylvania, Interview by phone, 21 March 1996.



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12. Mr. Morris Flater President, American Helicopter Society 217 North Washington St. Alexandria, Virginia 22314	1
13. Major William E. Taylor P.O. Box 33 Patuxent River, Maryland 20670	2